Appendix A: Cost and Macroeconomic Modeling

Introduction

The purpose of this appendix is to describe in detail the estimation of direct compliance costs associated with the CAA and the effect of those expenditures on U.S. economic conditions from 1970 to 1990. The first section of this appendix describes the dynamic, general equilibrium macroeconomic model used to examine economy-wide effects. Two broad categories of models were considered for use in the assessment: Macroeconomic forecasting models (e.g., the Data Resources Inc. model of the U.S. economy), and general equilibrium models (e.g., Hazilla and Kopp [1990], and Jorgenson and Wilcoxen [1990a]). The project team selected the Jorgenson-Wilcoxen (J/W) general equilibrium model of the United States for this analysis (Jorgenson and Wilcoxen [1990a]). There are two main reasons for choosing a dynamic general equilibrium approach: To capture both the direct and indirect economic effects of environmental regulation, and to capture the long-run dynamics of the adjustment of the economy. The general equilibrium framework enabled the project team to assess shifts in economic activity between industries, including changes in distributions of labor, capital, and other production factors within the economy, and changes in the distribution of goods and services.

The second section describes the data sources for direct compliance expenditures and presents estimates of historical air pollution control expenditures. These estimates are derived primarily from EPA's 1990 report entitled "Environmental Investments: The Cost of a Clean Environment"[1] (hereafter referred to as *Cost of Clean*). Specific adjustments to the *Cost of Clean* stationary source and mobile source O&M data needed to adapt these data for use in the present study are also described. These adjusted expenditure estimates represent the compliance cost data used as inputs to the J/W model to determine macroeconomic effects.

The final section presents a summary of the direct expenditure data, presents direct costs in a form that can be compared to the benefits estimates found elsewhere in the study, and discusses indirect effects arising from compliance expenditures estimated by the macroeconomic model. The indirect effects reported by the model are sectoral impacts and changes in aggregate measures of economic activity such as household consumption and gross national product. These indirect effects are second-order impacts of compliance expenditures — a parallel modeling exercise to estimate second-order economic impacts arising from the benefits of compliance (e.g., increased output as a result of improved longevity or fewer workdays lost as a result of non-fatal heart attacks) has not been attempted.

Macroeconomic Modeling

EPA analyses of the costs of environmental regulations typically quantify the direct costs of pollution abatement equipment and related operating and maintenance expenses. However, this approach does not fully account for all of the broader economic consequences of reallocating resources to the production and use of pollution abatement equipment. A general equilibrium, macroeconomic model could, in theory, capture the complex interactions between sectors in the economy and assess the full economic cost of air pollution control. This would be particularly useful for assessing regulations that may produce significant interaction effects between markets. Another advantage of a general equilibrium, macroeconomic framework is that it is internally consistent. The consistency of sectoral forecasts with realistic projections of U.S. economic growth is ensured since they are estimated within the context of a single model.[2] This contrasts

[1] Environmental Investments: The Cost of a Clean Environment, Report of the Administrator of the Environmental Protection Agency to the Congress of the United States, EPA-230-11-90-083, November 1990.

[2] In the present study, both benefits and costs are driven by of the same macroeconomic projections from the Jorgenson/Wilcoxen model, to ensure that the estimates are based on a consistent set of economic assumptions.

with typical EPA analyses that compile cost estimates from disparate sectoral and partial equilibrium models.

The economic effects of the CAA may be over- or underestimated, if general equilibrium effects are ignored, to the extent that sectors not directly regulated are affected. For example, it is well known that the CAA imposed significant direct costs on the energy industry. Economic sectors not directly regulated will nonetheless be affected by changes in energy prices. However, an examination of the broader effects of the CAA on the entire economy might reveal that the CAA also led to more rapid technological development and market penetration of environmentally "clean" renewable sources of energy (e.g., photovoltaics). These effects would partially offset adverse effects on the energy industry, and lead to a different estimate of the total economic cost to society of the CAA.

The significance of general equilibrium effects in the context of any particular analysis is an empirical question. Kokoski and Smith (1987) used a computable general equilibrium model to demonstrate that partial-equilibrium welfare measures can offer reasonable approximations of the true welfare changes for large exogenous changes. In contrast, the results of Jorgenson and Wilcoxen (1990a) and Hazilla and Kopp (1990) suggest that total pollution abatement in the U.S. has been a major claimant on productive resources, and the effect on long-run economic growth may be significant. Again, such conclusions must be considered in light of the limitations of general equilibrium models.

Choice of Macroeconomic Model

The adequacy of any model or modeling approach must be judged in light of the policy questions being asked. One goal of the present study is to assess the effects of clean air regulations on macroeconomic activity. Two broad categories of macroeconomic models were considered for use in the assessment: short run, Keynesian models and long-run, general equilibrium models.

Recognizing that structural differences exist between the models, one needs to focus in on the particular questions that should be answered with any particular model. The Congressional Budget Office (1990) noted:

> "Both the [Data Resources Incorporated] DRI and the IPCAEO models show relatively limited possibilities for increasing energy efficiency and substituting other goods for energy in the short run... Both models focus primarily on short-term responses to higher energy prices, and *neither is very good at examining how the structure of the economy could change in response to changing energy prices.* The [Jorgenson-Wilcoxen] model completes this part of the picture..."[3]

One strategy for assessing the macroeconomic effects of the CAA would be to use a DRI-type model in conjunction with the Jorgenson-Wilcoxen model to assess both the long-term effects and the short-run transitions, in much the same way that the Congressional Budget Office used these models to assess the effects of carbon taxes. However, because of significant difficulties in trying to implement the DRI model in a meaningful way, the project team chose to focus on the long-run effects of the CAA. Structural changes (e.g., changes in employment in the coal sector due to the CAA) can be identified with the Jorgenson-Wilcoxen model.

Overview of the Jorgenson-Wilcoxen Model

The discussion below focuses on those characteristics of the Jorgenson-Wilcoxen model that have important implications for its use in the assessment of environmental regulations (see Table A-1). The J/W model is a detailed dynamic general equilibrium model of the U.S. economy designed for medium run analysis of regulatory and tax policy (Jorgenson and Wilcoxen [1990a]). It provides projections of key macroeconomic variables, such as GNP and aggregate consumption, as well as energy flows between economic sectors. As a result, the model is particularly useful for examining how the structure of the economy could change in response to changes in re-

[3] The Congressional Budget Office report (1990) refers to an older (1981) version of the Jorgenson model, not the current (1988) version. The approach to long-run dynamics differs between the two models. The newer Jorgenson-Wilcoxen model contains both the capital accumulation equation and the capital asset pricing equation. The 1981 version of the model contained only the capital accumulation equation.

Table A-1. Key Distinguishing Characteristics of the Jorgenson-Wilcoxen Model.

- Dynamic, general equilibrium, macroeconomic model of the U.S. economy.
- Econometrically estimated using historic data.
- Free mobility of a single type of capital and labor between industries.
- Detailed treatment of production and consumption.
- Rigorous representation of savings and investment.
- Endogenous model of technical change.
- Does not capture unemployment, underemployment, or the costs of moving capital from one industry to another.

source prices. For the purpose of this study, it has five key features: a detailed treatment of production and consumption, parameters estimated econometrically from historical data, an endogenous model of technical change, a rigorous representation of saving and investment, and free mobility of labor and capital between industries.

The first two features, industry and consumer detail and econometric estimation, allow the model to capture the effects of the CAA at each point in time for given levels of technology and the size of the economy's capital stock. A detailed treatment of production and consumption is important because the principal effects of the Clean Air Act fell most heavily on a handful of industries. The J/W model divides total U.S. production into 35 industries which allows the primary economic effects of the CAA to be captured. Econometric estimation is equally important because it ensures that the behavior of households and firms in the model is consistent with the historical record.

The model's second two features —its representations of technical change and capital accumulation— complement the model's intratemporal features by providing specific information on how the Act affected technical change and the accumulation of capital. Many analyses of environmental regulations overlook or ignore intertemporal effects but these effects can be very important. Jorgenson and Wilcoxen (1990a) suggests that the largest cost of all U.S. environmental regulations together was that the regulations reduced the rate of capital accumulation.

The model's last feature, free mobility of a single type of capital and a single type of labor, is important because it limits the model's ability to measure the short run costs of changes in policy. J/W is a full-employment model that describes the long-run dynamics of transitions from one equilibrium to another. Capital and labor are both assumed to be freely mobile between sectors (that is, they can be moved from one industry to another at zero cost) and to be fully used at all times. Over the medium to long run, this is a reasonable assumption, but in the short run it is too optimistic. In particular, the model will understate the short run costs of a change in policy because it does not capture unemployment, underemployment, or the costs of moving capital from one industry to another. A single rate of return on capital exists that efficiently allocates the capital in each period among sectors. Similarly, a single equilibrium wage rate allocates labor throughout the economy.

Structure of the Jorgenson-Wilcoxen Model

The J/W model assesses a broad array of economic effects of environmental regulations. Direct costs are captured as increased expenditures on factors of production —capital, labor, energy and materials— that the various industries must make to comply with the regulations, as well as additional out-of-pocket expenditures that consumers must make. Indirect costs are captured as general equilibrium effects that occur throughout the economy as the prices of factors of production change (e.g., energy prices). Also, the rate of technological change can respond to changes in the prices of factors of production, causing changes in productivity (Jorgenson and Fraumeni, 1981).

The model is divided into four major sectors: the business, household, government, and rest-of-the-world sectors. The business sector is further subdivided into 35 industries (see Table A-2).[4] Each sector produces a primary product, and some produce secondary products. These outputs serve as inputs to the production processes of the other industries, are used for investment, satisfy final demands by the household and government sectors, and are exported. The model also allows for imports from the rest of the world.

[4] The 35 industries roughly correspond to a two-digit SIC code classification scheme.

Table A-2. Definitions of Industries Within the J/W Model.

Industry Number	Description
1	Agriculture, forestry, and fisheries
2	Metal mining
3	Coal mining
4	Crude petroleum and natural gas
5	Nonmetallic mineral mining
6	Construction
7	Food and kindred products
8	Tobacco manufacturers
9	Textile mill products
10	Apparel and other textile products
11	Lumber and wood products
12	Furniture and fixtures
13	Paper and allied products
14	Printing and publishing
15	Chemicals and allied products
16	Petroleum refining
17	Rubber and plastic products
18	Leather and leather products
19	Stone, clay, and glass products
20	Primary metals
21	Fabricated metal products
22	Machinery, except electrical
23	Electrical machinery
24	Motor vehicles
25	Other transportation equipment
26	Instruments
27	Miscellaneous manufacturing
28	Transportation and warehousing
29	Communication
30	Electric utilities
31	Gas utilities
32	Trade
33	Finance, insurance, and real estate
34	Other services
35	Government enterprises

The Business Sector

The model of producer behavior allocates the value of output of each industry among the inputs of the 35 commodity groups, capital services, labor services, and noncompeting imports. Output supply and factor demands of each sector are modeled as the results of choices made by wealth maximizing, price taking firms which are subject to technological constraints. Firms have perfect foresight of all future prices and interest rates. Production technologies are represented by econometrically estimated cost functions that fully capture factor substitution possibilities and industry-level biased technological change.

Capital and energy are specified separately in the factor demand functions of each industry. The ability of the model to estimate the degree of substitutability between factor inputs facilitates the assessment of the effect of environmental regulations. A high degree of substitutability between inputs implies that the cost of environmental regulation is low, while a low degree of substitutability implies high costs of environmental regulation. Also, different types of regulations lead to different responses on the part of producers. Some regulations require the use of specific types of equipment. Others regulations restrict the use of particular factor inputs; for example, through restrictions on the combustion of certain types of fuels. Both of these effects can change the rate of productivity growth in an industry through changes in factor prices.

The Household Sector

In the model of consumer behavior, consumer choices between labor and leisure and between consumption and saving are determined. A system of individual, demographically defined household demand functions are also econometrically estimated. Household consumption is modeled as a three stage optimization process. In the first stage households allocate lifetime wealth to full consumption in current and future time periods to maximize intertemporal utility. Lifetime wealth includes financial wealth, discounted labor income, and the imputed value of leisure. Households have perfect foresight of future prices and interest rates. In the second stage, for each time period full consumption is allocated between goods and services and leisure to maximize intratemporal utility. This yields an allocation of a household's time endowment between the labor market (giving rise to labor supply and labor income) and leisure time and demands for goods and services. In the third stage, personal consumption expenditures are allocated among capital, labor, noncompeting imports and the outputs of the 35 production sectors to maximize a subutility function for goods consumption. As with the business sector, substitution possibilities exist in consumption decisions. The model's flexibility enables it to capture the substitution of nonpolluting products for polluting ones that may be induced by environmental regulations. Towards this end, purchases of energy and capital services by households are specified separately within the consumer demand functions for individual commodities.

It is important to be clear regarding the notions of labor supply and demand within the J/W model, and what is meant by "employment" throughout this report. Labor demands and supplies are represented as quality-adjusted hours denominated in constant dollars. The labor market clears in each period; the quantity of labor services offered by households is absorbed fully by the economy's producing sectors. However, inferences regarding the number of persons employed require information on labor quality and work-hours per person over time and across simulations. Neither of these are explicitly modeled.

The Government Sector

The behavior of government is constrained by exogenously specified budget deficits. Government tax revenues are determined by exogenously specified tax rates applied to appropriate transactions in the business and household sectors. Levels of economic activity in these sectors are endogenously determined. Capital income from government enterprises (determined endogenously), and nontax receipts (given exogenously), are added to tax revenues to obtain total government revenues. Government expenditures adjust to satisfy the exogenous budget deficit constraint.

The Rest-of-the-World Sector

The current account balance is exogenous, limiting the usefulness of the model to assess trade competitiveness effects. Imports are treated as imperfect substitutes for similar domestic commodities and compete on price. Export demands are functions of foreign incomes and ratios of commodity prices in U.S. currency to the exchange rate. Import prices, foreign incomes, and tariff policies are exogenously specified. Foreign prices of U.S. exports are determined endogenously by domestic prices and the exchange rate. The exchange rate adjusts to satisfy the exogenous constraint on net exports.

Environmental Regulation, Investment, and Capital Formation

Environmental regulations have several important effects on capital formation. At the most obvious level, regulations often require investment in specific pieces of pollution abatement equipment. If the economy's pool of savings were essentially fixed, the need to invest in abatement equipment would reduce, or crowd out, investment in other kinds of capital on a dollar for dollar basis. On the other hand, if the supply of savings were very elastic then abatement investments might not crowd out other investment at all. In the J/W model, both the current account and government budget deficits are fixed exogenously so any change in the supply of funds for domestic investment must come from a change in domestic savings. Because households choose consumption, and hence savings, to maximize a lifetime utility function, domestic savings will be somewhat elastic. Thus, abatement investment will crowd out other investment, although not on a dollar for dollar basis.

The J/W assumption that the current account does not change as a result of environmental regulation is probably unrealistic, but it is not at all clear that this biases the crowding out effects in any particular direction. By itself, the need to invest in abatement capital would tend to raise U.S. interest rates and draw in foreign savings. To the extent this occurred, crowding out would be reduced. At the same time, however, regulation reduces the profitability of domestic firms. This effect would tend to lower the return on domestic assets, leading to a reduced supply of foreign savings which would exacerbate crowding out. Which effect dominates is an empirical question beyond the scope of this study.

In additional to crowding out ordinary investment, environmental regulation also has a more subtle effect on the rate of capital formation. Regulations raise the prices of intermediate goods used to produce new capital. This leads to a reduction in the number of capital goods which can be purchased with a given pool of savings. This is not crowding out in the usual sense of the term, but it is an important means by which regulation reduces capital formation.[5]

The General Equilibrium

The J/W framework contains intertemporal and intratemporal models (Jorgenson and Wilcoxen [1990c]). In any particular time period, all markets clear. This market clearing process occurs in response to any changes in the levels of variables that are speci-

[5] Wilcoxen (1988) suggests that environmental regulation may actually lead to a "crowding in" phenomenon. Wilcoxen examined the effects of regulation at the firm level, and introduced costs into the model related to the installation of capital. He found that when firms shut down their plants to install environmental capital, they take account of the adjustment costs and often concurrently replace other older capital equipment. This effect, however, is not captured in the current version of the Jorgenson-Wilcoxen model.

fied exogenously to the model. The interactions among sectors determine, for each period, aggregate domestic output, capital accumulation, employment, the composition of output, the allocation of output across different household types, and other variables.

The model also produces an intertemporal equilibrium path from the initial conditions at the start of the simulation to the stationary state. (A stationary solution for the model is obtained by merging the intertemporal and intratemporal models.) The dynamics of the J/W model have two elements: An accumulation equation for capital, and a capital asset pricing equation. Changes in exogenous variables cause several adjustments to occur within the model. First, the single stock of capital is efficiently allocated among all sectors, including the household sector. Capital is assumed to be perfectly malleable and mobile among sectors, so that the price of capital services in each sector is proportional to a single capital service price for the economy as a whole. The value of capital services is equal to capital income. The supply of capital available in each period is the result of past investment, i.e., capital at the end of each period is a function of investment during the period and capital at the beginning of the period. This capital accumulation equation is backward-looking and captures the effect of investments in all past periods on the capital available in the current period.

The capital asset pricing equation specifies the price of capital services in terms of the price of investment goods at the beginning and end of each period, the rate of return to capital for the economy as a whole, the rate of depreciation, and variables describing the tax structure for income from capital. The current price of investment goods incorporates an assumption of perfect foresight or rational expectations. Under this assumption, the price of investment goods in every period is based on expectations of future capital service prices and discount rates that are fulfilled by the solution of the model. This equation for the investment goods price in each time period is forward-looking.[6]

One way to characterize the J/W model —or any other neoclassical growth model— is that the short-run supply of capital is perfectly inelastic, since it is completely determined by past investment. However, the supply of capital is perfectly elastic in the long run. The capital stock adjusts to the time endowment, while the rate of return depends only on the intertemporal preferences of the household sector.

A predetermined amount of technical progress also takes place that serves to lower the cost of sectoral production. Finally, the quality of labor is enhanced, giving rise to higher productivity and lower costs of production.

Given all of these changes, the model solves for a new price vector and attains a new general equilibrium. Across all time periods, the model solves for the time paths of the capital stock, household consumption, and prices. The outcomes represent a general equilibrium in all time periods and in all markets covered by the J/W model.

Configuration of the No-control Scenario

One of the difficulties in describing the no-control scenario is ascertaining how much environmental regulation would have been initiated by state and local governments in the absence of a federal program. It may reasonably be argued that many state and local governments would have initiated their own control programs in the absence of a federal role. This view is further supported by the fact that many states and localities have, in fact, issued rules and ordinances which are significantly more stringent and encompassing than federal minimum requirements. However, it may also be argued that the federal CAA has motivated a substantial number of stringent state and local control programs.

Specifying the range and stringency of state and local programs that would have occurred in the absence of the federal CAA would be almost entirely speculative. For example, factors which would complicate developing assumptions about stringency and scope of unilateral state and local programs include: (i) the significance of federal funding to support state and local program development; (ii) the influence of more severe air pollution episodes which might be expected in the absence of federally-mandated controls; (iii) the potential emergence of pollution havens, as well as anti-pollution havens, motivated by local

[6] The price of capital assets is also equal to the cost of production, so that changes in the rate of capital accumulation result in an increase in the cost of producing investment goods. This has to be equilibrated with the discounted value of future rentals in order to produce an intertemporal equilibrium. The rising cost of producing investment is a cost of adjusting to a new intertemporal equilibrium path.

political and economic conditions; (iv) the influence of federally-sponsored research on the development of pollution effects information and control technologies; and (v) the need to make specific assumptions about individual state and local control levels for individual pollutants to allow estimation of incremental reductions attributable to federal control programs.

Another complication associated with the no-control scenario is the treatment of air pollution control requirements among the major trading partners of the U.S. Real-world manifestation of a no-control scenario would imply that public health and environmental goals were not deemed sufficiently compelling by U.S. policy makers. Under these conditions, major trading partners of the U.S. in Japan, Europe, and Canada may well reach similar policy conclusions. Simply put, if the U.S. saw no need for air pollution controls, there is little reason to assume other developed industrial countries would have either. In this case, some of the estimated economic benefits of reducing or eliminating air pollution controls in the U.S. would not materialize because U.S. manufacturers would not necessarily gain a production cost advantage over foreign competitors. However, like the question of state and local programs in the absence of a federal program, foreign government policies under a no-control scenario would be highly speculative.

Given the severity of these confounding factors, the only analytically feasible assumptions with respect to the no-control scenario are that (a) no new control programs would have been initiated after 1970 by the states or local governments in the absence of a federal role, and (b) environmental policies of U.S. trading partners remain constant regardless of U.S. policy.

Elimination of Compliance Costs in the No-Control Case

Industries that are affected by environmental regulations can generally respond in three ways: (i) with process changes (e.g., fluidized bed combustion); (ii) through input substitution (e.g., switching from high sulfur coal to low sulfur coal); and (iii) end-of-pipe abatement (e.g., the use of electrostatic precipitation to reduce the emissions of particulates by combustion equipment).[7] Clean air regulations have typically led to the latter two responses, especially in the short run. End-of-pipe abatement is usually the method of choice for existing facilities, since modifying existing production processes can be costly. This approach is also encouraged by EPA's setting of standards based on the notion of "best available technology" (Freeman, 1978).

All three possible responses may lead to: (i) unanticipated losses to equity owners; (ii) changes in current output; and (iii) changes in long-run profitability. If firms were initially maximizing profits, then any of the above three responses will increase its costs. Fixed costs of investment will be capitalized immediately. This will result in a loss to owners of equity when regulations are introduced. As far as firms are concerned, this is just like a lump sum tax on sunk capital. Such effects will not affect growth or efficiency. However, regulations could also change marginal costs and therefore current output. In addition, they could change profits (i.e., the earnings of capital), and thus affect investment. Both of these effects will reduce the measured output of the economy.

On the consumption side, environmental regulations change consumers' expectations of their lifetime wealth. In the no-control scenario of this assessment, lifetime wealth increases. This causes an increase in consumption. In fact, with perfect foresight, consumption rises more in earlier time periods. This also results in a change in savings.

Capital Costs - Stationary Sources

To appropriately model investment in pollution control requires a recognition that the CAA had two different effects on capital markets. First, CAA regulations led to the retrofitting of existing capital stock in order to meet environmental standards. In the no-control scenario, these expenditures do not occur. Instead, the resources that were invested in pollution abatement equipment to retrofit existing sources are available to go to other competing investments. Thus, at each point in time, these resources might go to investments in capital in the regulated industry, or may go into investments in other industries, depending upon relative rates of return on those investments. This will affect the processes of capital formation and deepening.

Second, the CAA placed restrictions on new sources of emissions. When making investment decisions, firms take into account the additional cost of pollution abatement equipment. Effectively, the

[7] Regulation may also affect the rate of investment, and change the rate of capital accumulation.

"price" of investment goods is higher because more units of capital are required to produce the same amount of output. In the no-control scenario, there are no restrictions on new sources and hence no requirements for pollution control expenditures. Effectively, the "price" of investment goods is lower. Thus, at each point in time, investors are faced with a lower price of investment goods. This results in a different profile for investment over time.

Operating and Maintenance Costs - Stationary Sources

In addition to purchasing pollution abatement equipment, firms incurred costs to run and maintain the pollution abatement equipment. In the no-control scenario, resources used to pay for these operating and maintenance (O&M) costs are freed up for other uses. The model assumes that the resources required to run and maintain pollution control equipment are in the same proportions as the factor inputs used in the underlying production technology. For example, if 1 unit of labor and 2 units of materials are used to produce 1 unit of output, then one-third of pollution control O&M costs are allocated to labor and two-thirds are allocated to materials. These adjustments were introduced at the sector level. O&M expenditures are exclusive of depreciation charges and offset by any recovered costs.

Capital Costs - Mobile Sources

Capital costs associated with pollution control equipment were represented by changing costs for motor vehicles (sector 24) and other transportation equipment (sector 26). Prices (unit costs) were reduced in proportion to the value of the pollution control devices contained in cars, trucks, motorcycles, and aircraft.

Operating and Maintenance - Mobile Sources

Prices for refined petroleum products (sector 16) were changed to reflect the resource costs associated with producing unleaded and reduced lead gasoline (fuel price penalty), the change in fuel economy for vehicles equipped with pollution control devices (fuel economy penalty), and the change in fuel economy due to the increased fuel density of lower leaded and no lead gasoline (fuel economy credit). Third, inspection and maintenance costs and a maintenance credit associated with the use of unleaded and lower leaded (i.e., unleaded and lower leaded gasoline is less corrosive, and therefore results in fewer muffler replacements, less spark plug corrosion, and less degradation of engine oil) were represented as changes in prices for other services (sector 34).

Direct Compliance Expenditures Data

Sources of Cost Data

Cost data for this study are derived primarily from the 1990 *Cost of Clean* report. EPA publishes cost data in response to requirements of the Clean Air and Clean Water Acts. The following subsections describe *Cost of Clean* data in detail, as well as adjustments made to the data and data from other sources.

Cost of Clean Data

EPA is required to compile and publish public and private costs resulting from enactment of the Clean Air Act and the Clean Water Act. The 1990 *Cost of Clean* report presents estimates of historical pollution control expenditures for the years 1972 through 1988 and projected future costs for the years 1989 through 2000. This includes federal, state, and local governments as well as the private sector. Estimates of capital costs, operation and maintenance (O&M) costs, and total annualized costs for five categories of environmental media, including air, water, land, chemical, and multi-media, are presented. It should be noted that these estimates represent direct regulatory implementation and compliance costs rather than social costs. The *Cost of Clean* relied on data from two governmental sources, the EPA and the U.S. Department of Commerce (Commerce).

EPA Data

EPA expenditures were estimated from EPA budget justification documents.[8] Estimates of capital and operating costs resulting from new and forthcoming regulations were derived from EPA's Regulatory Impact Analyses (RIAs). RIAs have been prepared prior to the issuance of all major regulations since 1981. Finally, special analyses conducted by EPA program offices or contractors were used when other data sources did not provide adequate or reliable data.

[8] The main source of data for EPA expenditures is the *Justification of Appropriation Estimates for Committee on Appropriations.*

Commerce Data

Data collected by Commerce were used extensively in the *Cost of Clean* for estimates of historical pollution control expenditures made by government agencies other than EPA and by the private sector. Two Commerce agencies, the Bureau of Economic Analysis (BEA) and the Bureau of the Census (Census), have collected capital and operating costs for compliance with environmental regulations since the early 1970's. Commerce is, in fact, the primary source of original survey data for environmental regulation compliance costs. Commerce publishes a number of documents that report responses to surveys and comprise most of the current domain of known pollution abatement and control costs in the United States, including:

- A series of articles entitled "Pollution Abatement and Control Expenditures" published annually in the *Survey of Current Business* by BEA (BEA articles);
- A series of documents entitled "Pollution Abatement Costs and Expenditures" published annually in the *Current Industrial Reports* by Census (PACE reports); and
- A series of documents entitled *Government Finances* published annually by Census (Government Finances).

BEA articles contain data derived from a number of sources, including two key agency surveys —the "Pollution Abatement Costs and Expenditures Survey" (PACE Survey) and the "Pollution Abatement Plant and Equipment Survey" (PAPE Survey)— which are conducted annually by Census for BEA. Data have been reported for 1972 through 1987.[9]

PACE reports have been published annually since 1973 with the exception of 1987. Figures for 1987 were estimated on the basis of historical shares within total manufacturing. These reports contain expenditure estimates derived from surveys of about 20,000 manufacturing establishments. Pollution abatement expenditures for air, water and solid waste are reported by state and Standard Industrial Code (SIC) at the four-digit level. According to Census, surveys conducted since 1976 have not included establishments with fewer than 20 employees because early surveys showed that they contributed only about 2 percent to the pollution estimates while constituting more than 10 percent of the sample size.

Each year Census conducts a survey of state, local, and county governments; and survey results are published in *Government Finances.* Census asks government units to report revenue and expenditures, including expenditures for pollution control and abatement.

Non-EPA Federal expenditures were estimated from surveys completed by federal agencies detailing their pollution control expenditures, which are submitted to BEA. Private sector air pollution control expenditures, as well as state and local government air pollution expenditures, were taken from BEA articles.

Stationary Source Cost Data

Capital Expenditures Data

Capital expenditures for stationary air pollution control are made by factories and electric utilities for plant and equipment that abate pollutants through end-of-line (EOL) techniques or that reduce or eliminate the generation of pollutants through changes in production processes (CIPP). For the purposes of this report EOL and CIPP expenditures are aggregated.[10] Table A-3 summarizes capital expenditures for stationary air pollution control, categorized as "nonfarm business" or "government enterprise" expenditures.

Nonfarm business capital expenditures consist of plant and equipment expenditures made by 1) manufacturing companies, 2) privately and cooperatively owned electric utilities, and 3) other nonmanufacturing companies. "Government enterprise" is, according to BEA, an agency of the government whose operating costs, to a substantial extent, are covered by the sale of goods and services. Here, government enterprise means specifically government enterprise electric

[9] The most recent BEA article used as a source for air pollution control costs in the Cost of Clean was "Pollution Abatement and Control Expenditures, 1984-87" in *Survey of Current Business*, June 1989.

[10] Survey respondents to the Census annual Pollution Abatement Surveys report the difference between expenditures for CIPP and what they would have spent for comparable plant and equipment without pollution abatement features. Disaggregated capital expenditures by private manufacturing establishments can be found in annual issues of Census reports.

Table A-3. Estimated Capital and O&M Expenditures for Stationary Source Air Pollution Control (millions of current dollars).

	Nonfarm Business		Government Enterprise	
Year	Cap.[a]	O&M[b]	Cap.[c]	O&M[d]
1972	2,172		63	
1973	2,968	1,407	82	29
1974	3,328	1,839	104	56
1975	3,914	2,195	102	45
1976	3,798	2,607	156	58
1977	3,811	3,163	197	60
1978	3,977	3,652	205	72
1979	4,613	4,499	285	106
1980	5,051	5,420	398	148
1981	5,135	5,988	451	135
1982	5,086	5,674	508	141
1983	4,155	6,149	422	143
1984	4,282	6,690	416	147
1985	4,141	6,997	328	189
1986	4,090	7,116	312	140
1987	4,179	7,469	277	130
1988	4,267	7,313	243	161
1989	4,760	7,743	235	173
1990	4,169	8,688	226	154

Sources:
a. Non-farm capital expenditures for 1972-87 are from *Cost of Clean*, Table B-1, line 2.
b. Non-farm O&M expenditures for 1973-85 are from *Cost of Clean*, Table B-1, line 8.
c. Government enterprise capital expenditures for 1972-87 are from *Cost of Clean*, Table B-9, line 1.
d. Government enterprise O&M expenditures for 1973-85 are from *Cost of Clean*, Table B-9, line 5.
All other reported expenditures are EPA estimates.

utilities. Government enterprise capital expenditures are pollution abatement expenditures made by publicly owned electric utilities.[11]

Operation and Maintenance Expenditures Data

Stationary source O&M expenditures are made by manufacturing establishments, private and public electric utilities, and other nonmanufacturing businesses to operate air pollution abatement equipment. O&M expenditures for electric utilities are made up of two parts: 1) expenditures for operating air pollution equipment and 2) the additional expenditures associated with switching to alternative fuels that have lower sulfur content (fuel differential). Expenditures to operate air pollution abatement equipment are for the collection and disposal of flyash, bottom ash, sulfur and sulfur products, and other products from flue gases.[12] O&M expenditures are net of depreciation and payments to governmental units, and are summarized in Table A-3. O&M data were disaggregated to the two digit SIC level for use in the macroeconomic model.

For both capital and O&M expenditures, historical survey data were not available for each year through 1990 prior to publication of *Cost of Clean*. For the purpose of the section 812 analysis, EPA projected 1988-1990 capital expenditures and 1986-1990 O&M expenditures. Those projections were used in the macroeconomic simulation, and have been retained as cost estimates to ensure consistency between the macroeconomic results and the direct cost estimates. Since completion of the macroeconomic modeling, however, BEA has published expenditure estimates through 1990. A comparison of more recent BEA estimates with the EPA projections used in the section 812 analysis can be found in the "Uncertainties in the Cost Analysis" section, below.

Recovered Costs

"Recovered costs" are costs recovered (i.e., revenues realized) by private manufacturing establishments through abatement activities. According to instructions provided to survey participants by Census, recovered costs consist of 1) the value of materials or energy reclaimed through abatement activities that were reused in production and 2) revenue that was obtained from the sale of materials or energy reclaimed through abatement activities. Estimates of recovered costs were obtained from the PACE reports and are summarized in Table A-4. In this analysis, recovered costs were removed from total stationary source air pollution control O&M costs — that is, net O&M cost in any year would be O&M expenditures (see Table A-3) less recovered costs. Recovered cost data were disaggregated to the two digit SIC level for use in the macroeconomic model.

[11] BEA calculates these expenditures using numbers obtained from Energy Information Agency (EIA) Form 767 on steam-electric plant air quality control.

[12] Farber, Kit D. and Gary L. Rutledge, "Pollution Abatement and Control Expenditures: Methods and Sources for Current-Dollar Estimates," Unpublished paper, Bureau of Economic Analysis, U.S. Department of Commerce, October 1989.

Table A-4. Estimated Recovered Costs for Stationary Source Air Pollution Control (millions of current dollars).

Year	PACE*	Estimated
1972		248
1973		199
1974		296
1975		389
1976		496
1977		557
1978		617
1979	750	750
1980	862	862
1981	1,000	997
1982	858	857
1983	822	822
1984	866	870
1985	767	768
1986	860	867
1987		987
1988	1,103	1,107
1989		1,122
1990		1,256

* Air cost recovered as reported in PACE
Source: "Pollution Abatement Costs and Expenditures" published annually in the Current Industrial Reports by Census.

Mobile Source Cost Data

Costs of controlling pollution emissions from motor vehicles were estimated by calculating the purchase price and O&M cost premiums associated with vehicles equipped with pollution abatement controls over the costs for vehicles not equipped with such controls. These costs were derived using EPA analyses, including EPA RIAs, the *Cost of Clean*, and other EPA reports.[13] This Appendix summarizes the section 812 mobile source compliance cost estimates and provides references to published data sources where possible. Further information on specific methods, analytical steps, and assumptions can be found in McConnell *et al.* (1995),[14] which provides a detailed description of the section 812 mobile source cost estimation exercise and compares the method and results to other similar analyses (including *Cost of Clean* (1990)).

Capital Expenditures Data

Capital expenditures for mobile source emission control are associated primarily with pollution abatement equipment on passenger cars, which comprise the bulk of all mobile sources of pollution. These capital costs reflect increasingly stringent regulatory requirements and improvements in pollution control technologies over time. Each of the following devices have been used at one time or another dating back to the Clean Air Act Amendments of 1965: air pumps, exhaust-gas recirculation valves, high altitude controls, evaporative emissions controls, and catalysts. The cost estimates for each component were computed on a per-vehicle basis by engineering cost analyses commissioned by EPA. The resulting per-vehicle capital costs were multiplied by vehicle production estimates to determine annual capital costs. Table A-5 summarizes mobile source capital costs.

Operation and Maintenance Expenditures Data

Costs for operation and maintenance of emission abatement devices include the costs of maintaining pollution control equipment plus the cost of vehicle inspection/maintenance programs. Operating costs per vehicle were multiplied by total vehicles in use to determine annual cost. Mobile source O&M costs are made up of three factors: 1) fuel price penalty, 2) fuel economy penalty, and 3) inspection and maintenance program costs as described below. These costs are mitigated by cost savings in the form of maintenance economy and fuel density economy. Table A-6 summarizes mobile source O&M expenditures and cost savings by categories, with net O&M costs summarized above in Table A-5. The following sections describe the components of the mobile source O&M cost estimates.

Fuel Price Penalty

Historically, the price of unleaded fuel has been several cents per gallon higher than the price of leaded fuel. CAA costs were calculated as the difference be-

[13] A complete listing of sources used in calculating mobile source capital and operating expenditures can be found in *Environmental Investments: The Cost of a Clean Environment*, Report of the Administrator of the Environmental Protection Agency to the Congress of the United State, EPA-230-11-90-083, November 1990.

[14] *Evaluating the Cost of Compliance with Mobile Source Emission Control Requirements: Retrospective Analysis*, Resources for the Future Discussion Paper, 1995. Note that McConnell *et al.* refer to the section 812 estimates as: *Cost of Clean* (1993, unpublished).

Table A-5. Estimated Capital and Operation and Maintenance Expenditures for Mobile Source Air Pollution Control (millions of current dollars).

Year	Capital[a]	O&M[b]
1973	276	1,765
1974	242	2,351
1975	1,570	2,282
1976	1,961	2,060
1977	2,248	1,786
1978	2,513	908
1979	2,941	1,229
1980	2,949	1,790
1981	3,534	1,389
1982	3,551	555
1983	4,331	-155
1984	5,679	-326
1985	6,387	337
1986	6,886	-1,394
1987	6,851	-1,302
1988	7,206	-1,575
1989	7,053	-1,636
1990	7,299	-1,816

Sources:
a. Capital exp.: *Cost of Clean*, Tables C-2 to C-9, line 3 on each; Tables C-2A to C-9A, line 10 on each; converted from $1986 to current dollars.
b. O&M exp.: EPA analyses based on sources and methods in: *Costs and Benefits of Reducing Lead in Gasoline: Final Regulatory Impact Analysis*, U.S. Environmental Protection Agency, Office of Policy Analysis, EPA-230-05-85-006, February 1985; and *Cost of Clean*.

tween the cost of making unleaded gasoline and leaded gasoline with lower lead levels and the cost of making only leaded gasoline with a lead content set at pre-regulatory levels. These cost estimates were developed using a linear programming model of the refinery industry. Prices of crude oil and other unfinished oils, along with the prices of refinery outputs, were adjusted annually according to price indices for imported crude oil over the period of analysis. The relative shares of leaded and unleaded gasoline and the average lead content in leaded gasoline also were adjusted annually according to the historical record.

These estimates may tend to understate costs due to a number of biases inherent in the analysis process. For example, the refinery model was allowed to optimize process capacities in each year. This procedure is likely to understate costs because regulatory requirements and market developments cannot be perfectly anticipated over time. This procedure resulted in estimates that are about ten percent less than estimates in other EPA reports.[15] However, new process technologies that were developed in the mid-1980s were not reflected in either the base case or regulatory case runs. It is reasonable to expect that regulatory requirements would have encouraged development of technologies at a faster rate than would have occurred otherwise.

Fuel Economy Penalty

The fuel economy penalty benefit is the cost associated with the increased/decreased amount of fuel used by automobiles with air pollution control devices (all else being equal). An assumption that can be made is that the addition of devices, such as catalytic con-

Table A-6. O&M Costs and Credits (millions of current dollars).

Year	Fuel Price Penalty	Fuel Econ. Penalty	Net I & M*	Total Costs
1973	91	1700	-26	1765
1974	244	2205	-98	2351
1975	358	2213	-289	2282
1976	468	2106	-514	2060
1977	568	1956	-738	1786
1978	766	1669	-1527	908
1979	1187	1868	-1826	1229
1980	1912	1998	-2120	1790
1981	2181	1594	-2386	1389
1982	2071	1026	-2542	555
1983	1956	628	-2739	-155
1984	2012	313	-2651	-326
1985	3057	118	-2838	337
1986	2505	-40	-3859	-1394
1987	2982	-158	-4126	-1302
1988	3127	-210	-4492	-1575
1989	3476	-318	-4794	-1636
1990	3754	-481	-5089	-1816

* Inspection and maintenance costs less fuel density savings and maintenance savings.

Sources: All results are presented in Jorgenson *et al.* (1993), pg. A.17. FPP results are based on a petroleum refinery cost model run for the retrospective analysis. FEP and Net I&M are based on data and methods from *Costs and Benefits of Reducing Lead in Gasoline: Final Regulatory Impact Analysis*, U.S. Environmental Protection Agency, Office of Policy Analysis, EPA-230-05-85-006, February 1985; and *Cost of Clean* (1990). Specific analytic procedures are summarized in McConnell *et al.* (1995).

[15] Costs and Benefits of Reducing Lead in Gasoline: Final Regulatory Impact Analysis, U.S. Environmental Protection Agency, Office of Policy Analysis, EPA-230-05-85-006, February 1985.

verters, decrease automobile fuel efficiency.[16] If this assumption is true, air pollution control devices increase the total fuel cost to consumers. An alternative assumption is that the use of catalytic converters has increased fuel economy. This increase has been attributed in large measure to the feedback mechanism built into three-way catalytic converters.[17] Under this assumption, the decrease in total fuel cost to consumers is considered a benefit of the program.

For the purposes of this study, sensitivity analyses were performed using data presented in the *Cost of Clean* report. These analyses were conducted to evaluate the significance of assumptions about the relationship between mile per gallon (MPG) values for controlled automobiles and MPG values for uncontrolled cars. Based on results of these and other analyses, fuel economy was assumed to be equal for controlled and uncontrolled vehicles from 1976 onward. This may bias the cost estimates although in an unknown direction.

Inspection and Maintenance Programs

Inspection and maintenance programs are administered by a number of states. Although these programs are required by the Clean Air Act, the details of administration were left to the discretion of state or local officials. The primary purpose of inspection and maintenance programs is to identify cars that require maintenance —including cars that 1) have had poor maintenance, 2) have been deliberately tampered with or had pollution control devices removed, or 3) have used leaded gasoline when unleaded is required— and force the owners of those cars to make necessary repairs or adjustments.[18] Expenditures for inspection and maintenance were taken from the *Cost of Clean.*

Beneficial effects of the mobile source control program associated with maintenance and fuel density were also identified. These cost savings were included in this study as credits to be attributed to the mobile source control program. Credits were estimated based on an EPA study,[19] where more detailed explanations may be found.

Maintenance Credits

Catalytic converters require the use of unleaded fuel, which is less corrosive than leaded gasoline. On the basis of fleet trials, the use of unleaded or lower leaded gasoline results in fewer muffler replacements, less spark plug corrosion, and less degradation of engine oil, thus reducing maintenance costs. Maintenance credits account for the majority of the direct (non-health) economic benefits of reducing the lead concentration in gasoline.

Fuel Density Credits

The process of refining unleaded gasoline increases its density. The result is a gasoline that has higher energy content. Furthermore, unleaded gasoline generates more deposits in engine combustion chambers, resulting in slightly increased compression and engine efficiency. Higher energy content of unleaded gasoline and increased engine efficiency from the used of unleaded gasoline yield greater fuel economy and therefore savings in refining, distribution, and retailing costs.

Other Direct Cost Data

The *Cost of Clean* report includes several other categories of cost that are not easily classified as either stationary source or mobile source expenditures. Federal and state governments incur air pollution abatement costs; additionally, federal and state governments incur costs to develop and enforce CAA regulations. Research and development expenditures by the federal government, state and local governments, and (especially) the private sector can be attributed to the CAA. These data are summarized by year in Table A-7.

Unlike the other private sector expenditure data used for this analysis, the survey data used as a source for private sector R&D expenditures cannot be disaggregated into industry-specific expenditure totals. Consequently, private sector R&D expenditures are

[16] Memo from Joel Schwartz (EPA/OPPE) to Joe Somers and Jim DeMocker dated December 12, 1991, and entitled “Fuel Economy Benefits.” Schwartz states that since this analysis is relative to a no Clean Air Act baseline, not a 1973 baseline, fuel economy benefits are not relevant. In the absence of regulation, tuning of engines for maximum economy would presumably be optimal in the base case as well.

[17] Memo from Joseph H. Somers, EPA Office of Mobile Sources, to Anne Grambsch (EPA/OPPE) and Joel Schwartz (EPA/OPPE) entitled “Fuel Economy Penalties for section 812 Report,” December 23, 1991.

[18] Walsh, Michael P., “Motor Vehicles and Fuels: The Problem,” *EPA Journal*, Vol. 17, No. 1, January/February 1991, p. 12.

[19] Schwartz, J., *et al. Costs and Benefits of Reducing Lead in Gasoline: Final Regulatory Impact Analysis,* U. S. Environmental Protection Agency, Economic Analysis Division, Office of Policy Analysis, February 1985.

Table A-7. Other Air Pollution Control Expenditures (millions of current dollars).

Year	Abatement		Regulations and Monitoring		Research and Development			Total
	Fed.[a]	State & Local[b]	Fed.[c]	State & Local[d]	Private[e]	Fed.[f]	State & Local[g]	
1973	47	0	50	115	492	126	6	836
1974	56	0	52	131	520	100	7	866
1975	88	1	66	139	487	108	8	897
1976	105	1	69	135	562	131	6	1,009
1977	106	1	80	161	675	144	7	1,174
1978	90	0	93	183	805	146	8	1,325
1979	103	0	100	200	933	105	7	1,448
1980	95	0	122	207	851	130	5	1,410
1981	85	0	108	226	798	131	0	1,348
1982	87	0	93	230	761	126	2	1,229
1983	136	4	88	239	691	133	6	1,297
1984	115	14	101	250	665	165	4	1,314
1985	98	12	103	250	775	247	3	1,488
1986	67	14	106	307	833	217	4	1,548
1987	80	15	110	300	887	200	2	1,594
1988	65	10	120	320	934	220	1	1,670
1989	70	12	130	360	984	230	2	1,788
1990	71	13	133	343	749	231	2	1,542

Sources:
a. Federal government abatement expenditures: 1973-82, "Pollution Abatement and Control Expenditures", Survey of Current Business (BEA) July 1986 Table 9 line 13; 1983-87, BEA June 1989 Table 7 line 13; 1988-90, BEA May 1995 Table 7 line 13.
b. State and local abatement expenditures: 1973-87, *Cost of Clean*, Table B-9 line 2; 1988-90, BEA May 1995 Table 7 line 14.
c. Federal government "regs/monitoring" expenditures: 1973-82, BEA July 1986, Table 9 line 17; 1983-87, BEA June 1989 Table 6 line 17; 1988-90, BEA May 1995 Table 7 line 17.
d. State and local government "regs/monitoring" expenditures: 1973-87, *Cost of Clean*, Table B-9 line 3; 1988-90, BEA May 1995 Table 7 line 18.
e. Private sector R&D expenditures: 1973-86, BEA May 1994 Table 4 (no line #) [total R&D expenditures in $1987 are converted to current dollars using the GDP price deflator series found elsewhere in this Appendix -- netting out public sector R&D leaves private sector expenditures]; 1987-90, BEA May 1995 Table 7 line 20.
f. Federal government R&D expenditures: 1973-82, BEA July 1986 Table 9 line 21; 1983-87, BEA June 1989 Table 6 line 21; 1988-90, BEA May 1995, Table 7 line 21.
g. State and local government R&D expenditures: 1973-87, *Cost of Clean*, Table B-9 line 4; 1988-90, BEA May 1995 Table 7 line 22.

omitted from the macroeconomic modeling exercise (the macro model is industry-specific). The R&D expenditures are, however, included in aggregate cost totals used in the benefit-cost analysis.

The *Cost of Clean* and the series of articles "Pollution Abatement and Control Expenditures" in the Survey of Current Business (various issues) are the data sources for "Other Air Pollution Control Expenditures." State and local expenditures through 1987 are found in *Cost of Clean*; 1988-90 expenditures are from more recent issues of the Survey of Current Business (BEA). Federal government expenditures are from BEA (various issues). Private R&D expenditures were reported in *Cost of Clean*. Since publication of *Cost of Clean*, however, BEA has revised its private sector R&D expenditure series (BEA, 1994 and 1995). Since private R&D expenditures were not included in the macroeconomic modeling exercise, the revised series can be (and has been) used without causing inconsistency with other portions of the section 812 analysis.

Assessment Results

Compliance Expenditures and Costs

Compliance with the CAA imposed direct costs on businesses, consumers, and governmental units, and triggered other expenditures such as governmental regulation and monitoring costs and expenditures for research and development by both government and industry. As shown in Table A-8, annual CAA compliance expenditures – including R&D, etc.– over the period from 1973 to 1990 were remarkably stable[20], ranging from about $20 billion to $25 billion in inflation-adjusted 1990 dollars (expenditures are adjusted to 1990 dollars through application of the GDP Implicit Price Deflator). This is equal to approximately one third of one percent of total domestic output during that period, with the percentage falling from one half of one percent of total output in 1973 to one quarter of one percent in 1990.

Although useful for many purposes, a summary of direct annual expenditures is not the best cost measure to use when comparing costs to benefits. Capital expenditures are investments, generating a stream of benefits (and opportunity cost) over the life of the investment. The appropriate accounting technique to use for capital expenditures in a cost/benefit analysis is to *annualize* the expenditure — i.e., to spread the capital cost over the useful life of the investment, applying a discount rate to account for the time value of money.

[20] While total expenditures remained relatively constant over the period, the sector-specific data presented in Tables A-3 and A-5 above indicate that capital expenditures for stationary sources fell significantly throughout the period but that this decline was offset by significant increases in mobile source capital expenditures.

Table A-8. Summary of Expenditures and Conversion to 1990 Dollars (millions of dollars).

	CURRENT YEAR DOLLARS								1990 DOLLARS						
	Stationary		Rec.	Mobile Source			TOTAL	GDP price	Stationary		Rec.	Mobile Source			TOTAL
	K	O&M	Costs	K	O&M	Other	EXP	defl.	K	O&M	Costs	K	O&M	Other	EXP
1972	2,235	na	na	na	na	na	na	38.8	6,521						
1973	3,050	1,436	199	276	1,765	836	7,164	41.3	8,360	3,936	545	756	4,838	2,290	19,635
1974	3,432	1,895	296	242	2,351	866	8,490	44.9	8,653	4,778	746	610	5,927	2,184	21,405
1975	4,016	2,240	389	1,570	2,282	897	10,616	49.2	9,240	5,154	895	3,612	5,250	2,063	24,425
1976	3,954	2,665	496	1,961	2,060	1,009	11,153	52.3	8,558	5,768	1,074	4,244	4,459	2,183	24,139
1977	4,008	3,223	557	2,248	1,786	1,174	11,882	55.9	8,116	6,527	1,128	4,552	3,617	2,378	24,062
1978	4,182	3,724	617	2,513	908	1,325	12,035	60.3	7,851	6,991	1,158	4,718	1,705	2,487	22,593
1979	4,898	4,605	750	2,941	1,229	1,448	14,371	65.5	8,465	7,959	1,296	5,083	2,124	2,503	24,837
1980	5,449	5,568	862	2,949	1,790	1,410	16,304	71.7	8,603	8,791	1,361	4,656	2,826	2,226	25,741
1981	5,586	6,123	997	3,534	1,389	1,348	16,983	78.9	8,014	8,785	1,430	5,070	1,993	1,935	24,367
1982	5,594	5,815	857	3,551	555	1,299	15,957	83.8	7,557	7,855	1,158	4,797	750	1,755	21,555
1983	4,577	6,292	822	4,331	(155)	1,297	15,520	87.2	5,942	8,168	1,067	5,622	(201)	1,684	20,148
1984	4,698	6,837	870	5,679	(326)	1,314	17,332	91	5,844	8,505	1,082	7,064	(406)	1,634	21,560
1985	4,469	7,186	768	6,387	337	1,488	19,099	94.4	5,359	8,617	921	7,659	404	1,785	22,903
1986	4,402	7,256	867	6,886	(1,394)	1,548	17,831	96.9	5,142	8,477	1,013	8,044	(1,628)	1,809	20,831
1987	4,456	7,599	987	6,851	(1,302)	1,594	18,211	100	5,044	8,602	1,117	7,755	(1,474)	1,804	20,615
1988	4,510	7,474	1,107	7,206	(1,575)	1,670	18,178	103.9	4,914	8,143	1,206	7,851	(1,716)	1,819	19,805
1989	4,995	7,916	1,122	7,053	(1,636)	1,788	18,994	108.5	5,211	8,259	1,171	7,359	(1,707)	1,865	19,817
1990	4,395	8,842	1,256	7,312	(1,816)	1,542	19,019	113.2	4,395	8,842	1,256	7,312	(1,816)	1,542	19,019

K = Capital expenditures; O&M = Operation and Maintenance expenditures.
Rec. Costs = recovered costs. Total expenditures are the sum of stationary source, mobile source, and "other" expenditures, less recovered costs.
Stationary source expenditures are the sum of "Nonfarm Business" and "Government Enterprise" expenditures (from Table A-3).
To calculate expenditures in 1990 dollars, current year expenditures are multiplied by the ratio of the 1990 price deflator to the current year deflator. For example, 1989 expenditures are multiplied by (113.2/108.5).
Source for price deflator series: Economic Report of the President, February 1995, Table B-3.

Annualization Method

For this cost/benefit analysis, all capital expenditures have been annualized at 3 percent, 5 percent, and 7 percent (real) rates of interest. Therefore, "annualized" costs reported for any given year are equal to O&M expenditures (plus R&D, etc., expenditures, minus recovered costs) plus amortized capital costs (i.e., depreciation plus interest costs associated with the pre-existing capital *stock*) for that year. Stationary source air pollution control capital costs are amortized over twenty years; mobile source air pollution control costs are amortized over ten years. Capital expenditures are amortized using the formula for an annuity [that is, $r/(1-(1+r)^{-t})$, where r is the rate of interest and t is the amortization period].[21] Multiplying the expenditure by the appropriate annuity factor gives a constant annual cost to be incurred for t years, the present value of which is equal to the expenditure.

Due to data limitations, the cost analysis for this CAA retrospective starts in 1973, missing costs incurred in 1970-72. *Cost of Clean*, however, includes stationary source capital expenditures for 1972. In this analysis, amortized costs arising from 1972 capital investments *are included* in the 1973-1990 annualized costs, even though 1972 costs are not otherwise included in the analysis. Conversely, only a portion of the (e.g.) 1989 capital expenditures are reflected in the 1990 annualized costs — the remainder of the costs are spread through the following two decades, which fall outside of the scope of this study (similarly, benefits arising from emission reductions in, e.g., 1995 caused by 1990 capital investments are not captured by the benefits analysis). Table A-9 presents CAA compliance costs from 1973 to 1990, in 1990 dollars, with capital expenditures amortized at a five percent real interest rate. "Total" costs are the sum of stationary source, mobile source, and "other" costs, minus recovered costs.

Tables A-10 and A-11 provide details of the amortization calculation (using a five percent interest rate) for stationary sources and mobile sources, respectively. Similar calculations were performed to derive the annualized cost results using discount rates of three percent and seven percent.

The Stationary Source table reports a capital expenditure of $6,521 million for 1972 (in 1990 dollars). The cost is spread over the following twenty years (which is the assumed useful life of the investment) using a discount rate of five percent; thus, the amortization factor to be used is f(20)=0.0802. Multiplying $6,521 million by 0.0802 gives an annuity of $523 million. That annuity is noted on the first data row of the table, signifying that the 1972 expenditure of $6,521 million implies an annual cost of $523 million for the entire twenty-year period of 1973 to 1992 (the years following 1990 are not included on the tables, since costs incurred in those years are not included in this retrospective assessment). The first summary row near the bottom of the table (labeled "SUM") reports aggregate annualized capital costs: for 1973 (the first data column), capital costs are $523 million.

Capital expenditures in 1973 amounted to $8,360 million. Using the amortization technique explained above, one can compute an annualized cost of $671 million, incurred for the twenty-year period of 1974 to 1993. Aggregate annualized capital costs for 1974 include cost flows arising from 1972 and 1973 invest-

Table A-9. Annualized Costs, 1973-1990 (millions of 1990 dollars; capital expenditures annualized at 5 percent).

	Stationary		rec.	Mobile Source			
	K	O&M	costs	K	O&M	other	Total
1973	523	3,936	545	0	4,838	2,290	11,042
1974	1,194	4,778	746	98	5,927	2,184	13,435
1975	1,888	5,154	895	177	5,250	2,063	13,638
1976	2,630	5,768	1,074	645	4,459	2,183	14,611
1977	3,317	6,527	1,128	1,194	3,617	2,378	15,904
1978	3,968	6,991	1,158	1,784	1,705	2,487	15,776
1979	4,598	7,959	1,296	2,395	2,124	2,503	18,282
1980	5,277	8,791	1,361	3,053	2,826	2,226	20,812
1981	5,967	8,785	1,430	3,656	1,993	1,935	20,905
1982	6,610	7,855	1,158	4,313	750	1,755	20,125
1983	7,217	8,168	1,067	4,934	(201)	1,684	20,734
1984	7,694	8,505	1,082	5,564	(406)	1,634	21,909
1985	8,163	8,617	921	6,400	404	1,785	24,447
1986	8,593	8,477	1,013	6,924	(1,628)	1,809	23,161
1987	9,005	8,602	1,117	7,416	(1,474)	1,804	24,237
1988	9,410	8,143	1,206	7,831	(1,716)	1,819	24,281
1989	9,804	8,259	1,171	8,237	(1,707)	1,865	25,288
1990	10,222	8,842	1,256	8,531	(1,816)	1,542	26,066

Source: Stationary source capital costs and mobile source capital costs are from Tables A-10 and A-11, respectively. All other costs and offsets are from Table A-8.

[21] Using an interest rate of five percent, the factor for a twenty year amortization period is 0.0802; that for a ten year amortization period is 0.1295.

Table A-10. Amortization of Capital Expenditures for Stationary Sources (millions of 1990 dollars).

	EXPEND	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
1972	6,521	523	523	523	523	523	523	523	523	523	523	523	523	523	523	523	523	523	523
1973	8,360		671	671	671	671	671	671	671	671	671	671	671	671	671	671	671	671	671
1974	8,653			694	694	694	694	694	694	694	694	694	694	694	694	694	694	694	694
1975	9,240				741	741	741	741	741	741	741	741	741	741	741	741	741	741	741
1976	8,558					687	687	687	687	687	687	687	687	687	687	687	687	687	687
1977	8,116						651	651	651	651	651	651	651	651	651	651	651	651	651
1978	7,851							630	630	630	630	630	630	630	630	630	630	630	630
1979	8,465								679	679	679	679	679	679	679	679	679	679	679
1980	8,603									690	690	690	690	690	690	690	690	690	690
1981	8,014										643	643	643	643	643	643	643	643	643
1982	7,557											606	606	606	606	606	606	606	606
1983	5,942												477	477	477	477	477	477	477
1984	5,844													469	469	469	469	469	469
1985	5,359														430	430	430	430	430
1986	5,142															413	413	413	413
1987	5,044																405	405	405
1988	4,914																	394	394
1989	5,211																		418
1990	4,395																		
SUM		523	1,194	1,888	2,630	3,317	3,968	4,598	5,277	5,967	6,610	7,217	7,694	8,163	8,593	9,005	9,410	9,804	10,222
Expenditures		8,360	8,653	9,240	8,558	8,116	7,851	8,465	8,603	8,014	7,557	5,942	5,844	5,359	5,142	5,044	4,914	5,211	4,395
K stock		6,521	14,880	23,533	32,773	41,331	49,448	57,299	65,763	74,366	82,381	89,937	95,879	101,723	107,082	112,225	117,269	122,182	127,394
K stock net depr.		6,521	14,684	22,876	31,372	38,869	45,612	51,776	58,232	64,469	69,740	74,173	76,606	78,587	79,713	80,249	80,300	79,819	79,217
Int		326	734	1,144	1,569	1,943	2,281	2,589	2,912	3,223	3,487	3,709	3,830	3,929	3,986	4,012	4,015	3,991	3,961
Depr		197	460	745	1,061	1,373	1,687	2,009	2,365	2,744	3,123	3,508	3,863	4,233	4,607	4,993	5,395	5,813	6,262

Capital expenditures for each year are found in the "EXPEND" column. Expenditures are amortized over 20 years (i.e., years (t+1) to (t+20)) using a 5% real interest rate to derive a constant cost per year for the entire amortization period. The present value (in year t) of the cost flow is equal to the expenditure in year t. Annualized CAA compliance capital cost for each year (displayed in row "SUM") is the sum of the annuities calculated for capital expenditures from previous years. The capital stock ("K stock") in place at the start of each year is equal to the sum of expenditures from previous years. Subtracting depreciation from the capital stock leaves "K stock net depr." Annual interest expense is 5% of net capital stock. Annual interest expense plus depreciation equals annualized compliance cost (row "SUM").

Table A-11. Amortization of Capital Expenditures for Mobile Sources (millions of 1990 dollars).

	EXPEND	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
1972	0																	
1973	756	98	98	98	98	98	98	98	98	98	98							
1974	610		79	79	79	79	79	79	79	79	79	79						
1975	3,612			468	468	468	468	468	468	468	468	468	468					
1976	4,244				550	550	550	550	550	550	550	550	550	550				
1977	4,552					590	590	590	590	590	590	590	590	590	590			
1978	4,718						611	611	611	611	611	611	611	611	611	611		
1979	5,083							658	658	658	658	658	658	658	658	658	658	
1980	4,656								603	603	603	603	603	603	603	603	603	603
1981	5,070									657	657	657	657	657	657	657	657	657
1982	4,797										621	621	621	621	621	621	621	621
1983	5,622											728	728	728	728	728	728	728
1984	7,064												915	915	915	915	915	915
1985	7,659													992	992	992	992	992
1986	8,044														1,042	1,042	1,042	1,042
1987	7,755															1,004	1,004	1,004
1988	7,851																1,017	1,017
1989	7,359																	953
1990	7,312																	
SUM		98	177	645	1,194	1,784	2,395	3,053	3,656	4,313	4,934	5,564	6,400	6,924	7,416	7,831	8,237	8,531
Expenditures		610	3,612	4,244	4,552	4,718	5,083	4,656	5,070	4,797	5,622	7,064	7,659	8,044	7,755	7,851	7,359	7,312
K stock		756	1,367	4,979	9,223	13,776	18,493	23,576	28,232	33,302	38,099	42,965	49,419	53,466	57,266	60,469	63,602	65,878
K stock net depr.		756	1,306	4,807	8,647	12,437	15,993	19,480	22,057	24,574	26,287	28,289	31,204	34,023	36,845	39,026	40,997	42,169
Int		38	65	240	432	622	800	974	1,103	1,229	1,314	1,414	1,560	1,701	1,842	1,951	2,050	2,108
Depr		60	112	404	762	1,162	1,595	2,079	2,553	3,084	3,620	4,150	4,840	5,223	5,574	5,880	6,187	6,423

Capital expenditures for each year are found in the "EXPEND" column. Expenditures are amortized over 10 years (i.e., years (t+1) to (t+10)) using a 5% real interest rate to derive a constant cost per year for the entire amortization period. The present value (in year t) of the cost flow is equal to the expenditure in year t. Annualized CAA compliance capital cost for each year (displayed in row "SUM") is the sum of the annuities calculated for capital expenditures from previous years. The capital stock ("K stock") in place at the start of each year is equal to the sum of expenditures from the previous ten years. The sum of all previous expenditures less depreciation leaves "K stock net depr." Annual interest expense is 5% of net capital stock. Annual interest expense plus depreciation equals annualized compliance cost (row "SUM").

ments: that is, $523 million plus $671 million, or $1,194 million (see the "SUM" row). Similar calculations are conducted for every year through 1990, to derive aggregate annualized capital costs that increase monotonically from 1973 to 1990, even though capital expenditures decline after 1975.[22]

An alternative calculation technique is available that is procedurally simpler but analytically identical to that outlined above. Instead of calculating an annuity for each capital expenditure (by multiplying the expenditure by the annuity factor *f*), then summing the annuities associated with all expenditures in previous years, one can sum all previous expenditures and multiply the sum (i..e., the capital stock at the start of the year) by *f*. The third summary row (labeled "K stock") near the bottom of the amortization summary tables give the pollution control capital stock at the start of each year. For example, the stationary sources capital stock in place at the start of 1975 was $23,533 million (this is the sum of 1972, 1973, and 1974 capital expenditures). Multiplying the capital stock by the annuity factor 0.0802 gives $1,888 million, which is the aggregate annualized stationary source capital cost for 1975.

One can perform further calculations to decompose the annualized capital costs into "interest" and "financial depreciation" components.[23] For example, at the start of 1973, the stationary source capital stock was $6,521 million. A five percent interest rate implies an "interest expense" for 1973 of $326 million. Given a 1973 annualized cost of $523 million, this implies a "depreciation expense" for that year of ($523 million minus $326 million =) $197 million. For 1974, the existing capital stock net of "financial depreciation" was $14,684 million (that is, the $6,521 million in place at the start of 1973, plus the investment of $8,360 million during 1973, minus the depreciation of $197 million during 1973); five percent of $14,684 million is the interest expense of $734 million. Since the annualized capital cost for 1974 is $1,194 million, depreciation expense is $460 million (i.e., the difference between annualized cost and the interest component of annualized cost). This procedure is repeated to determine interest and depreciation for each year through 1990 (see the last three rows of Table A-11).

The three tables above all present costs (and intermediate calculations) assuming a five percent interest rate. As noted above, the Project Team also employed rates of three percent and seven percent to calculate costs. Those calculations and intermediate results are not replicated here. The method employed, however, is identical to that employed to derive the five percent results (with the only difference being the interest rate employed in the annuity factor calculation). Table A-12 presents a summary of expenditures and annualized costs at the three interest rates.

Table A-12. Compliance Expenditures and Annualized Costs, 1973-1990 ($1990 millions).

		Annualized Costs		
Year	Expend.	at 3%	at 5%	at 7%
1973	19,635	10,957	11,042	11,134
1974	21,405	13,231	13,435	13,655
1975	24,425	13,314	13,638	13,988
1976	24,139	14,123	14,611	15,139
1977	24,062	15,253	15,904	16,608
1978	22,593	14,963	15,776	16,653
1979	24,837	17,309	18,282	19,331
1980	25,741	19,666	20,812	22,046
1981	24,367	19,590	20,905	22,321
1982	21,555	18,643	20,125	21,720
1983	20,148	19,095	20,734	22,498
1984	21,560	20,133	21,909	23,819
1985	22,903	22,516	24,447	26,523
1986	20,831	21,109	23,161	25,364
1987	20,615	22,072	24,237	26,562
1988	19,805	22,012	24,281	26,719
1989	19,817	22,916	25,288	27,836
1990	19,019	23,598	26,066	28,717

Discounting Costs and Expenditures

The stream of costs from 1973 to 1990 can be expressed as a single cost number by *discounting* all costs to a common year. In this analysis, all costs and benefits are discounted to 1990 (in addition, all costs and benefits are converted to 1990 dollars, removing the effects of price inflation).[24] There is a broad range

[22] Similar calculations were performed for mobile source control capital costs, where the assumed amortization period is ten years.

[23] One might, for example, wish to examine the relative importance of the "time value" component of the computed capital costs.

[24] Unlike most cost-benefit analyses, where future expected costs and benefits are discounted back to the present, this exercise brings past costs closer to the present. That is, the discounting procedure used here is actually compounding past costs and benefits.

of opinion in the economics profession regarding the appropriate discount rate to use in analyses such as this. Some economists believe that the appropriate rate is one that approximates the social rate of time preference — three percent, for example (all rates used here are "real", i.e., net of price inflation impacts). Others believe that a rate that approximates the opportunity cost of capital (e.g., seven percent or greater) should be used. A third school of thought holds that some combination of the social rate of time preference and the opportunity cost of capital is appropriate, with the combination effected either by use of an intermediate rate or by use of a multiple-step procedure which uses the social rate of time preference as the "discount rate," but still accounts for the cost of capital. The section 812 Project Team chose to use a range of discount rates (three, five, and seven percent) for the analysis.

Expenditures and annualized costs discounted to 1990 are found on Table A-13. Expenditures are discounted at all three rates; annualized costs are discounted at the rate corresponding to that used in the annualization procedure (i.e., the "annualized at 3%" cost stream is discounted to 1990 at three percent). The final row presents the result of an explicit combination of two rates: Capital costs are annualized at seven percent, then the entire cost stream is discounted to 1990 at three percent.

Table A-13. Costs Discounted to 1990 ($1990 millions).

	3%	5%	7%
Expenditures	520,475	627,621	760,751
Annualized Costs	416,804	522,906	657,003
Annualized at 7%	476,329		

Indirect Economic Effects of the CAA

In addition to imposing direct compliance costs on the economy, the CAA induced indirect economic effects, primarily by changing the size and composition of consumption and investment flows. Although this analysis does not add these indirect effects to the direct costs and include them in the comparison to benefits, they are important to note. This section summarizes the most important indirect economic effects of the CAA, as estimated by the J/W macroeconomic simulation.

GNP and Personal Consumption

Under the no-control scenario, the level of GNP increases by one percent in 1990 relative to the control case (see Table A-14). During the period 1973-1990, the percent change in real GNP rises monotonically from 0.26 percent to 1.0 percent. The increase in the level of GNP is attributable to a rapid accumulation of capital, which is driven by changes in the price of investment goods. The capital accumulation effect is augmented by a decline in energy prices relative to the base case. Lower energy prices that correspond to a world with no CAA regulations decreases costs and increases real household income, thus increasing consumption.

Table A-14. Differences in Gross National Product Between the Control and No-control Scenarios.

Year	Nominal % Change	Real % Change
1973	-0.09	0.26
1974	-0.18	0.27
1975	-0.10	0.44
1976	-0.00	0.49
1977	-0.10	0.54
1978	-0.16	0.56
1979	-0.16	0.63
1980	-0.14	0.69
1981	-0.14	0.73
1982	-0.19	0.74
1983	-0.19	0.78
1984	-0.17	0.84
1985	-0.12	0.95
1986	-0.14	0.98
1987	-0.15	1.01
1988	-0.20	1.00
1989	-0.21	0.99
1990	-0.18	1.00

Removing the pollution control component of new capital is equivalent to lowering the marginal price of investment goods. Combining this with the windfall gain of not having to bring existing capital into compliance leads to an initial surge in the economy's rate of return, raising the level of real investment. The investment effects are summarized in Figure A-1. More rapid (ordinary) capital accumulation leads to a decline in the rental price of capital services which, in turn, stimulates the demand for capital services by producers *and* consumers. The capital rental price reductions also serve to lower the prices of goods and services and, so, the overall price level. Obviously, the more capital intensive sectors exhibit larger price reductions.[25] The price effects from investment changes are compounded by the cost reductions associated with releasing resources from the operation and maintenance of pollution control equipment and by the elimination of higher prices due to regulations on mobile sources.

To households, no-control scenario conditions are manifest as an increase in permanent future real earnings which supports an increase in real consumption in all periods and, generally, an increase in the demand for leisure (see Table A-15). Households marginally reduce their offer of labor services as the income effects of higher real earnings dominate the substitution effects of lower goods prices. The increase in consumption is dampened by an increase in the rate of return that produces greater investment (and personal savings).

Table A-15. Difference in Personal Consumption Between the Control and No-Control Scenarios.

Year	Nominal % Change	Real % Change
1973	-0.02	0.33
1974	-0.01	0.43
1975	-0.10	0.24
1976	-0.10	0.39
1977	-0.10	0.54
1978	-0.09	0.63
1979	-0.11	0.68
1980	-0.12	0.71
1981	-0.13	0.74
1982	-0.12	0.81
1983	-0.13	0.85
1984	-0.15	0.86
1985	-0.19	0.88
1986	-0.19	0.94
1987	-0.19	0.98
1988	-0.17	1.03
1989	-0.17	1.04
1990	-0.18	1.01

Finally, technical change is a very important aspect of the supply-side adjustments under the no-control scenario. Lower factor prices increase the endogenous rates of technical change in those industries that are factor-using. Lower rental prices for capital benefit the capital-using sectors, lower materials prices benefit the materials-using sectors, and lower energy prices benefit the energy-using sectors. On balance, a significant portion of the increase in economic growth is attributable to accelerated productivity growth. Under the no-control scenario, economic growth averages 0.05 percentage points higher over the interval 1973-1990. The increased availability of capital accounts for 60 percent of this increase while faster productivity growth accounts for the remaining 40 percent. Thus, the principal effect arising from the costs associated with CAA initiatives is to slow the economy's rates of capital accumulation and productivity growth. This finding is consistent with recent analyses suggesting a potential association between higher reported air, water, and solid waste pollution abatement costs and lower plant-level productivity in some manufacturing industries (Gray and Shadbegian, 1993 and 1995).

As with the cost and expenditure data presented above, it is possible to present the stream of GNP and consumption changes as single values by discounting the streams to a single year. Table A-16 summarizes the results of the discounting procedure, and also includes discounted expenditure and annualized cost data for reference. Accumulated (and discounted to 1990) losses to GNP over the 1973-1990 period were half again as large as expenditures during the same period, and approximately twice as large as annualized costs. Losses in household consumption were approximately as great as annualized costs.

Table A-16. GNP and Consumption Impacts Discounted to 1990 ($1990 billions).

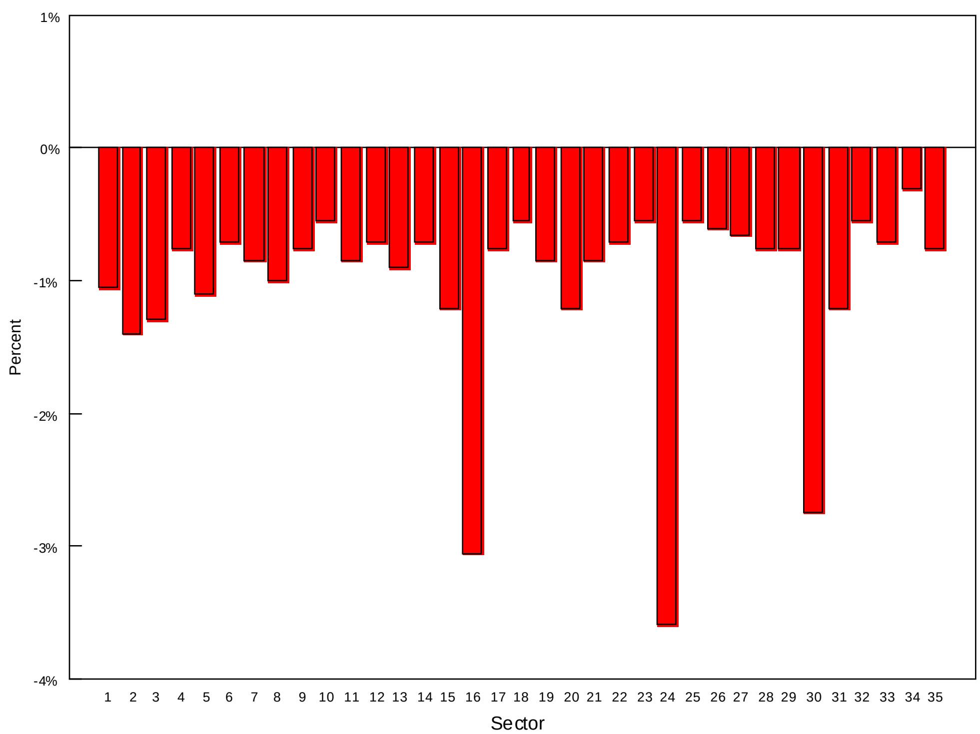
	3%	5%	7%
Expenditures	520	628	761
Annualized Costs	417	523	657
GNP	880	1005	1151
Household Consumption	500	569	653
HH and Gov't Consumption	676	769	881

Source: Expenditures and annualized costs from above; macroeconomic impacts from Jorgenson et al. (1993), Table 4.1

[25] Not surprisingly, at the industry level, the principal beneficiaries in the long run of eliminating the costs associated with air pollution abatement are the most heavily regulated industries. The largest changes in industry prices and outputs occur in the motor vehicles industry. Other industries that benefit significantly from the elimination of environmental controls are refined petroleum products, electric utilities, and other transportation equipment. Turning to manufacturing industries, metal mining and the primary metals have the largest gains in output from elimination of air pollution controls.

Figure A-1. Percent Difference in Real Investment Between Control and No-control Scenarios.

Figure A-2. Percent Difference in Price of Output by Sector Between Control and No-control Scenario for 1990.



Although they have value as descriptors of the magnitude of changes in economic activity, neither GNP nor consumption changes are perfect measures of changes in social welfare. A better measure is Equivalent Variations (EVs), which measure the change in income that is equivalent to the change in (lifetime) welfare due to removal of the CAA. As part of its macroeconomic exercise, EPA measured the EVs associated with removal of the CAA. Elimination of CAA compliance costs (disregarding benefits) represents a welfare gain of $493 billion to $621 billion, depending on assumptions used in the analysis.[26] This result does not differ greatly from the range of results represented by expenditures, anualized costs, and consumption changes.

Prices

One principal consequence of the Clean Air Act is that it changes prices. The largest price reductions accrue to the most heavily regulated industries which are the large energy producers and consumers (see Table A-17). But these are also the most capital intensive sectors and it is the investment effects that are the dominant influences in altering the course of the economy. Focusing on energy prices, under the no-control scenario the price of coal in 1990 declines by 1.3 percent, refined petroleum declines by 3.03 percent, electricity from electric utilities declines by 2.75 percent, and the price of natural gas from gas utilities declines by 1.2 percent. The declining price of fossil fuels induces substitution toward fossil fuel energy sources and toward energy in general. Total Btu consumption also increases.

Table A-17. Percentage Difference in Energy Prices Between the Control and No-control Scenarios.

Year	Coal	Refined Petroleum	Electric Utilities	Gas Utilities
1973	-0.44	-5.99	-2.11	-0.32
1974	-0.47	-4.84	-2.53	-0.44
1975	-0.42	-4.28	-2.19	-0.31
1976	-0.57	-3.83	-2.12	-0.44
1977	-0.74	-3.43	-2.22	-0.59
1978	-0.86	-3.28	-2.39	-0.68
1979	-0.91	-2.92	-2.81	-0.71
1980	-0.94	-2.76	-2.97	-0.69
1981	-0.97	-2.50	-2.76	-0.71
1982	-0.98	-2.42	-2.63	-0.77
1983	-1.09	-2.35	-2.58	-0.85
1984	-1.12	-2.26	-2.49	-0.91
1985	-1.21	-2.89	-2.62	-0.97
1986	-1.27	-3.35	-2.69	-1.12
1987	-1.31	-3.50	-2.78	-1.18
1988	-1.30	-3.61	-2.75	-1.19
1989	-1.31	-3.45	-2.74	-1.19
1990	-1.30	-3.03	-2.75	-1.20

Sectoral Effects: Changes in Prices and Output by Industry

At the commodity level, the effect of the CAA varies considerably. Figure A-2 shows the changes in the supply price of the 35 commodities measured as changes between the no-control case and the control-case for 1990.

In 1990, the largest change occurs in the price of motor vehicles (commodity 24), which declines by 3.8 percent in the no-control case. Other prices showing significant effects are those for refined petroleum products (commodity 16) which declines by 3.0 percent, and electricity (commodity 30) which declines 2.7 percent. Eight of the remaining industries have decreases in prices of 1.0 to 1.4 percent under the no-control scenario. The rest are largely unaffected by environmental regulations, exhibiting price decreases between 0.3 and 0.8 percent.

To assess the intertemporal consequences of the CAA, consider the model's dynamic results and the adjustment of prices between 1975 and 1990. Initially, in 1975, the biggest effect is on the price of output from petroleum refining (sector 16), which declines by 4.3 percent. But by 1990, the price of petroleum refining is about 3.0 percent below control scenario levels. In contrast, the price of motor vehicles (sector 24) is about 2.4 percent below baseline levels in 1975, but falls to about 3.8 percent below baseline levels in 1990.

The price changes affect commodity demands, which in turn determine how industry outputs are affected. Figure A-3 shows percentage changes in quantities produced by the 35 industries for 1990. As noted earlier, the principal beneficiaries under the no-control scenario are the most heavily regulated industries: motor vehicles, petroleum refining, and electric utilities.

In 1990, the motor vehicle sector (sector 24) shows the largest change in output, partly due to the fact that the demand for motor vehicles is price elastic. Recall

[26] Jorgenson et al., 1993.

Figure A-3. Percent Difference in Quantity of Output by Sector Between Control and No-control Scenario for 1990.

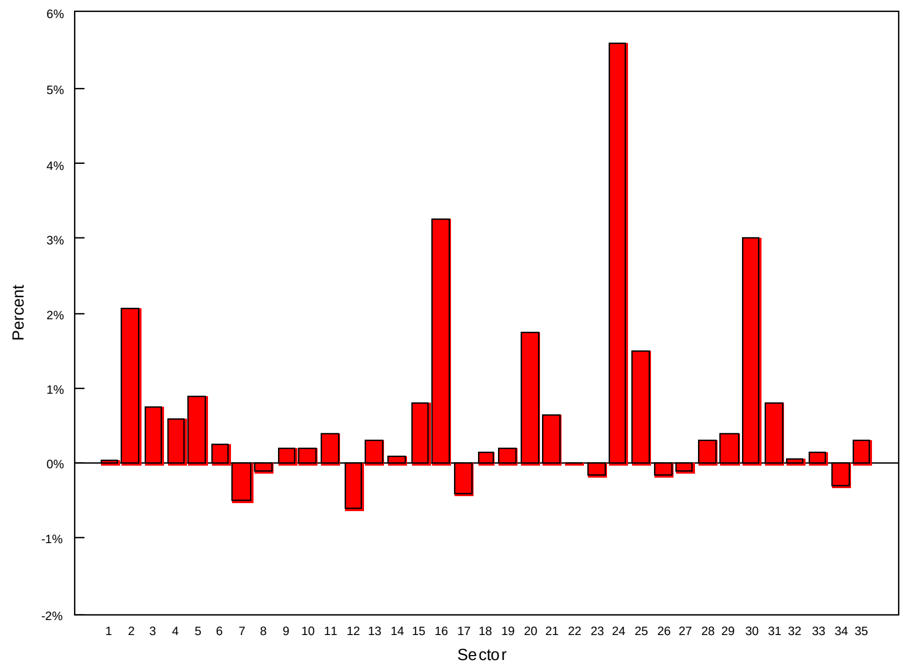
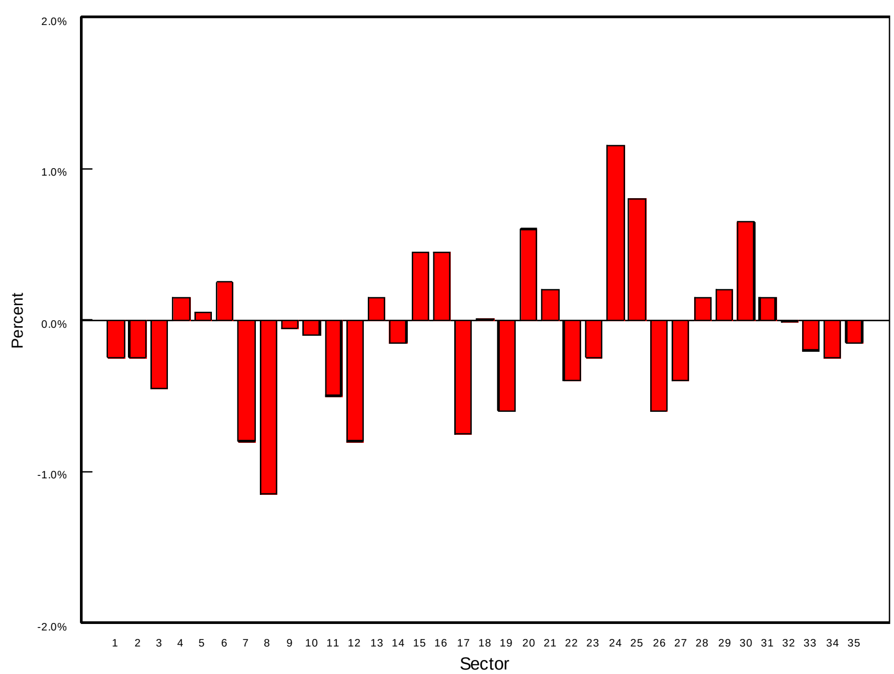


Figure A-4. Percent Difference in Employment by Sector Between Control and No-control Scenario for 1990.



that the largest increase in prices also occurred in the motor vehicles sector. The 3.8 percent reduction in prices produces an increase in output of 5.3 percent relative to the base case.

Significant output effects are also seen in the petroleum refining sector (sector 16) with a 3.2 percent increase, in electricity (sector 30) with a 3.0 percent increase, and in other transportation equipment (sector 25) with a 1.6 percent increase. The large gains in output for these industries are mostly due to the decline in their prices. In manufacturing, the sectors exhibiting the most significant output effects are metal mining (sector 2) with a 2.0 percent increase, and primary metals (sector 20) with a 1.8 percent increase. Twenty of the remaining industries exhibit increase in output of less than 0.9 percent after pollution controls are removed.

While most sectors increase output under the no-control scenario, a few sectors decline in size in the absence of air pollution controls. The most notable of these are food and kindred products (sector 7) which decline by 0.5 percent, furniture and fixtures (sector 12) which decline by 0.6 percent, and rubber and plastic products (sector 17) which decline by 0.3 percent. These sectors are among the least capital intensive, so the fall in the rental price of capital services has little effect on the prices of outputs. Buyers of the commodities produced by these industries face higher relative prices and substitute other commodities in both intermediate and final demand. The rest of the sectors are largely unaffected by environmental regulations.

Changes in Employment Across Industries

The effect of the CAA on employment presents a much more complicated picture. Although Jorgenson-Wilcoxen is a full-employment model and cannot be used to simulate unemployment effects, it is useful for gaining insights about changes in the patterns of employment across industries. Percentage changes in employment by sector for 1990 are presented in Figure A-4.

For 1990, the most significant changes in the level of employment relative to the control scenario occur in motor vehicles (sector 24) which increases 1.2 percent, other transportation equipment (sector 25) which increases 0.8 percent, electric utilities (sector 30) which increases 0.7 percent, and primary metals (sector 20) which increases 0.6 percent. The level of employment is higher relative to the control case in 10 other industries.

For a few sectors, the no-control scenario results in changes in real wages which cause *reductions* in employment. The most notable reductions in employment under the no-control scenario occur in tobacco manufacturing (sector 8) which declines 1.2 percent, furniture and fixtures (sector 12) which declines 0.8 percent, rubber and plastic products (sector 17) which declines 0.8 percent, food and kindred products (sector 7) which declines 0.7 percent, stone, clay and glass products (sector 19) which declines 0.6 percent, and instruments (sector 26) which declines 0.6 percent. These sectors are generally those in which the level of output was lower in 1990 relative to the control scenario, since they are among the least capital intensive and the fall in the rental price of capital services has little effect on the prices of outputs. Buyers of the commodities produced by these industries face higher relative prices and substitute other commodities in both intermediate and final demand. It is interesting to note that several of the least capital intensive sectors experience insignificant employment effects in the short run (1975) under the no-control scenario, but increasingly adverse effects over the 20-year period of analysis. These include food and kindred products, furniture and fixtures, rubber and plastic products, stone, clay and glass products, and instruments.

Examination of the transition of employment in the economy from the initial equilibrium to 1990 reveals that the employment effects of the CAA on motor vehicles, transportation equipment, electric utilities, and primary metals persist over the entire period of analysis. Employment varies from: an increase of 1.7 percent in 1975 to 1.2 percent in 1990 in motor vehicles; an increase of 0.7 in 1975 to 0.8 percent in 1990 in transportation equipment; an increase of 1.2 percent in 1975 to 0.7 percent in 1990 in electric utilities; and an increase of 0.8 percent in 1975 to 0.6 percent in 1990.

Uncertainties in the Cost Analysis

Potential Sources of Error in the Cost Data

Because of the importance of the *Cost of Clean* data for this assessment, the project team investigated potential sources of error due to the use of industry's self-reported costs of compliance with air pollution abatement requirements. Concerns about the accuracy of responses include (1) misreporting by firms in response to federal agency surveys, and (2) omission of important categories of compliance cost from the data collected or reported by these federal agencies.[27] Table A-18 contains a summary of the results of the analysis. This analysis is consistent with the findings of two recent studies comparing combined air, water, and solid waste pollution abatement costs, as reported in federal abatement cost surveys, to their observed effects on productivity levels. These studies suggest that, since observed productivity decreases exceed those expected to result from the reported abatement costs, there may be additional pollution abatement costs not captured or reported in the survey data, and that total abatement costs for the three manufacturing industries studied may be under-reported by as much as a factor of two in the most extreme case (Gray and Shadbegian, 1993 and 1995; Gray, 1996).

The major finding from this analysis indicates that total O&M costs are likely to be under-reported due to exclusion of private research and development

Table A-18. Potential Sources of Error and Their Effect on Total Costs of Compliance.

Source of Error	Effect on Capital Costs	Effect on O&M Costs
Lack of Data at Firm Level	Under-reported Percent Unknown	Under-reported Percent Unknown
Misallocation of Costs:		
Inclusion of OSHA and Other Regulatory Costs	Over-reported Percent Unknown	Over-reported Percent Unknown
Exclusion of Solid Waste Disposal Costs Related to Air Pollution Abatement	—	Under-reported Percent Unknown
Exclusion of Costs:		
Exclusion of Private R&D Expenses	—	Under-reported by 14 to 17% (varies by year)
Exclusion of Energy Use by Pollution Abatement Devices[a]	—	Under-reported by 1 to 3% (varies by year)
Exclusion of Depreciation Expenses[a]	—	Under-reported by 1 to 2% (varies by year)
Exclusion of Recovered Costs	—	Over-reported by 1% Plus
Omission of Small Firms	Under-reported by 1 to 2%	Under-reported by 1 to 2%
NET EFFECT	Under-reported	Under-reported

[a] Energy outlays *are* part of the data on O&M costs and depreciation expenses *are not*. Accordingly, in the J/W model, energy outlays are considered along with other operating expenditures in terms of their impacts on unit costs. Depreciation is represented fully in the capital accumulation process, as the undepreciated capital stock at the beginning of any period gives rise to the flow of capital services available to producers and consumers.

Source: Industrial Economics, Incorporated, memorandum to Jim DeMocker, EPA/OAR, "Sources of Error in Reported Costs of Compliance with Air Pollution Abatement Requirements," October 16, 1991.

[27] Memorandum from Industrial Economics, Incorporated to Jim DeMocker (EPA/OAR) dated 10/16/91 and entitled "Sources of Error in Reported Costs of Compliance with Air Pollution Abatement Requirements."

(R&D) expenditures. Note, however, that although these costs were excluded from those used for the macroeconomic modeling, they were included in the overall direct cost estimate of the CAA; see "Other Direct Costs," above. These costs are excluded from the macromodeling because they cannot be disaggregated by industry and, more importantly, because there is no information on what was purchased or obtained as a result of these expenditures.

Based on the need indicated by the IEc review, modifications to the BEA data were made to remedy some of the biases noted above. In particular, recovered costs for stationary source air pollution, e.g. sulfur removed using scrubbers that is then sold in the chemical market, have been accounted for in the data set used in the model runs.

Table A-19. Stationary Source O&M Expenditures as a Percentage of Capital Stock (millions of 1990 dollars).

				O&M divided by:	
	K stock	Net K	O&M	K stock	Net K
1973	6,521	6,521	3,936	0.60	0.60
1974	14,880	14,684	4,778	0.32	0.33
1975	23,533	22,876	5,154	0.22	0.23
1976	32,773	31,372	5,768	0.18	0.18
1977	41,331	38,869	6,527	0.16	0.17
1978	49,448	45,612	6,991	0.14	0.15
1979	57,299	51,776	7,959	0.14	0.15
1980	65,763	58,232	8,791	0.13	0.15
1981	74,366	64,469	8,785	0.12	0.14
1982	82,381	69,740	7,855	0.10	0.11
1983	89,937	74,173	8,168	0.09	0.11
1984	95,879	76,606	8,505	0.09	0.11
1985	101,723	78,587	8,617	0.08	0.11
1986	107,082	79,713	8,477	0.08	0.11
1987	112,225	80,249	8,602	0.08	0.11
1988	117,269	80,300	8,143	0.07	0.10
1989	122,182	79,819	8,259	0.07	0.10
1990	127,394	79,217	8,842	0.07	0.11

"K stock" is the accumulated undepreciated stationary source control capital stock available at the beginning of each year, from Table A-10.
"Net K" is the stationary source control capital stock less depreciation implied by amortization at 5%; from Table A-10.
"O&M" is the stationary source control O&M expenditures; from Table A-9.
The final two columns are ratios: O&M divided by capital stock; and O&M divided by net capital.

An additional set of concerns relates directly to reporting of costs by firms. Some have noted an unexpected temporal pattern of stationary source control expenditures in the BEA data that might lead one to question the accuracy of the Census survey responses. One would expect that stationary source O&M expenditures over time would be roughly proportional to the accumulated stationary source control capital stock. Yet, as illustrated in Table A-19, O&M expenditures as a fraction of accumulated capital stock decline over time (even if one discounts the first few years because of the dramatic percentage increases in capital stock during those years). It is true that the ratio of O&M expenditures to the *depreciated* capital stock (in the far right column, labeled "net K") is reasonably stable after 1981. The depreciation shown here, however, is a *financial* depreciation only, depicting the declining value of a piece of equipment over time, rather than a measure of physical asset shrinkage. Assuming a twenty-year useful lifetime, *all* of the stationary source control capital stock put in place since 1972 could conceivably still be in place in 1990. If anything, one would expect the O&M/K ratio to *increase* as the capital depreciates (i.e., ages), until the equipment is scrapped, because aging equipment requires increasing maintenance. Consequently, one might infer from this information that firms have systematically under-reported O&M expenditures, or have over-reported capital expenditures.

The apparent anomaly might be explained by an examination of the types of O&M expenditures reported. If more than a token percentage of O&M expenditures are unrelated to "operation and maintenance" of pollution control devices, then the observed O&M/K ratio would not appear unusual.

The Census PACE survey[28] required respondents to report air pollution abatement O&M expenses in the following categories: salaries and wages; fuel and electricity; contract work; and materials, leasing, and "miscellaneous."[29] In later versions of the survey, additional information relating to the types of expenses to report was provided as a guide to respondents. The types of expenses listed that are relevant to air pollution abatement include:

[28] *Pollution Abatement Costs and Expenditures*, various years.

[29] Census also requested a reporting of "depreciation" expenses as a component of O&M. BEA, however, removed depreciation expense from the reported O&M costs because retaining depreciation would have amounted to double-counting, since BEA also reported capital expenditures.

(1) operating and maintaining pollution abatement equipment;
(2) fuel and power costs for operating pollution abatement equipment;
(3) parts for pollution abatement equipment replacement and repair;
(4) testing and monitoring of emissions;
(5) incremental costs for consumption of environmentally preferable materials and fuels;
(6) conducting environmental studies for development or expansion;
(7) leasing of pollution abatement equipment;
(8) compliance and environmental auditing;
(9) salaries and wages for time spent completing environmental reporting requirements; and
(10) developing pollution abatement operating procedures.[30]

The magnitude of the expenditures associated with the first three items should be correlated with the size of the existing stock of air pollution abatement capital. Expenditures associated with items four through ten, however, should be independent of the size of the existing capital stock (expenditures associated with item seven, leasing of pollution abatement equipment, could be negatively correlated with the size of the capital stock). *If* items four through ten account for a non-negligible proportion of total O&M expenditures, and *if* respondents included these cost categories even though they were not explicitly listed in the survey instructions before 1991, *then* one would expect to see the O&M/K ratio declining during the study period. Thus, even though it is possible that O&M expenditures are underreported (or that capital expenditures are overreported), one cannot be certain.

Table A-20. Comparison of EPA and BEA Stationary Source Expenditure Estimates (millions of current dollars).

	Private sector		Gov't. Enterprise		Total
Year	capital	O&M	capital	O&M	Expend.
	EPA Estimates				
1986	4,090	7,116	312	140	11,658
1987	4,179	7,469	277	130	12,055
1988	4,267	7,313	243	161	11,984
1989	4,760	7,743	235	173	12,911
1990	4,169	8,688	226	154	13,237
	BEA Estimates				
1986	4,090	7,072	312	182	11,656
1987	3,482	5,843	246	141	9,712
1988	3,120	6,230	121	161	9,632
1989	3,266	6,292	229	152	9,939
1990	4,102	6,799	200	154	11,255

"Recovered Costs" are not included in this table.
Sources for "BEA Estimates": for 1986, "Pollution Abatement and Control Expenditures," Survey of Current Business (BEA) June 1989, Table 7; for 1987-90, BEA May 1995, Table 8.

Mobile Source Costs

For the section 812 analysis, EPA used the best available information on the estimated cost of mobile source air pollution control. Several other sources of cost estimates exist, however, including a cost series produced by the Department of Commerce Bureau of Economic Analysis (BEA). The BEA cost series is summarized in Table A-20. The BEA estimates differ significantly from EPA estimates, particularly with respect to estimates of capital costs and the "fuel price penalty" associated with the use of unleaded gasoline.

EPA's capital cost estimates are based on estimates of the cost of equipment required by mobile source regulations. BEA's estimates are based on survey data from the Bureau of Labor Statistics (BLS) that measures the increase in the per-automobile cost (relative to the previous model year) due to pollution control and fuel economy changes for that model year. The difference in approach is significant: BEA's annual capital cost estimates exceed EPA's by a factor of (roughly) two. EPA may underestimate costs to the extent that engineering cost estimates of components exclude design and development costs for those components. The BLS estimates add the incremental annual costs to all past costs to derive total current-year costs. Such an approach overestimates costs to the extent that it fails to account for cost savings due to changes in component mixes over time.

Some mobile source pollution control devices required the use of unleaded fuel. Unleaded gasoline is more costly to produce than is leaded gasoline, and generally has a greater retail price, thus imposing a cost on consumers. EPA estimated the "fuel price penalty" by using a petroleum refinery cost model to determine the expected difference in production cost between leaded and unleaded gasoline. BEA's "fuel price penalty" was the difference between the retail price of unleaded gasoline and that of leaded gasoline.

A detailed description of the data sources, analytic methods, and assumptions that underlie the EPA and BEA mobile source cost estimates can be found in McConnell et al. (1995).

[30] *Pollution Abatement Costs and Expenditures, 1992*, pg. A-9.

Stationary Source Cost Estimate Revisions

As noted above, the costs used for stationary sources in the macro-modeling (and retained in this cost analysis) were projected for several years in the late 1980s. Since that time, BEA has released historical expenditure estimates for those years based on survey data. A comparison of the expenditure series can be found in Table A-21. Apparently, EPA's projections overestimated stationary source compliance expenditures by approximately $2 billion per year for the period 1987-1990. Since expenditures from all sources are estimated to be $18 billion -$19 billion (current dollars) per year during 1987-1990, this implies that EPA has overestimated compliance expenditures by more than ten percent during this period. Although a substantial overstatement for those years, the $2 billion per year overestimate would have little impact (probably less than two percent) on the discounted present value, in 1990 dollars, of the 1973-1990 expenditure stream.

Table A-21. BEA Estimates of Mobile Source Costs.

Year	Capital Exp.	Net I&M*	Fuel Price Penalty	Fuel Economy Penalty
1973	1,013	1,104		697
1974	1,118	1,380	5	1,180
1975	2,131	1,520	97	1,344
1976	2,802	1,420	309	1,363
1977	3,371	1,289	701	1,408
1978	3,935	1,136	1,209	1,397
1979	4,634	931	1,636	1,792
1980	5,563	726	2,217	2,320
1981	7,529	552	2,996	2,252
1982	7,663	409	3,518	1,876
1983	9,526	274	4,235	1,582
1984	11,900	118	4,427	1,370
1985	13,210	165	4,995	1,133
1986	14,368	(331)	4,522	895
1987	13,725	(453)	3,672	658
1988	16,157	(631)	3,736	420
1989	15,340	(271)	1,972	183
1990	14,521	(719)	1,370	(55)

* Inspection and maintenance costs less fuel density savings and maintenance savings.

Endogenous Productivity Growth in the Macro Model

For each industry in the simulation, the JW model separates price-induced changes in factor use from changes resulting strictly from technical change. Thus, simulated productivity growth for each industry has two components: (a) an exogenous component that varies over time, and (b) an endogenous component that varies with policy changes. Some reviewers have noted that, although not incorrect, use of endogenous productivity growth is uncommon in the economic growth literature. EPA conducted a sensitivity run of the J/W model, setting endogenous growth parameters to zero (i.e., removing endogenous productivity growth from the model).[31]

Endogenous productivity growth is an important factor in the J/W model. For example, for the period 1973-1990, removal of the endogenous productivity growth assumptions reduces household income by 2.9 to 3.0 percent (depending on whether one uses a world with CAA or one without CAA as the baseline). In comparison, removal of CAA compliance costs results in a 0.6 to 0.7 percent change in household income (depending on whether one uses, as a baseline, a world with or one without endgenous productivity growth). That is, use of the endogenous productivity growth assumption has four to five times the impact of that of CAA compliance costs.

Although very important to the simulated growth of the economy within any policy setting, the endogenous productivity growth assumption is less important across policy settings. Under the base (i.e., "with endogenous productivity growth") scenario, the aggregate welfare effect (measured as EVs, see above) of CAA compliance costs and indirect effects is estimated to be 493 billion to 621 billion in 1990 dollars. If one removes the endogenous productivity growth assumption, the aggregate welfare effect declines to the range 391 billion to 494 billion in 1990 dollars (Jorgenson et al., 1993, pg. 6-15), a reduction of about twenty percent.

[31] For greater detail, see Jorgenson et al., 1993.

Amortization Period for Stationary Source Plant and Equipment

In developing annualized costs, stationary source capital expenditues were amortized over a twenty-year period. That is, it was assumed that plant and equipment would depreciate over twenty years. It is possible that stationary source plant and equipment has, on average, a useful lifetime significantly greater than twenty years. The Project Team tested the sensitivity of the cost analysis results to changes in stationary source capital amortization periods.

Table A-22 presents total annualized compliance costs assuming a 40-year amortization period for stationary source capital expenditures (all other cost components are unchanged from the base analysis). All costs are in 1990-value dollars, ad three alternative discount rates are used in the annualization period. Table A-23 presents the results discounted to 1990, and compared to the base case results (i.e., using a twenty-year amortization period). Doubling the amortization period to 40 years decreases the 1990 present value of the 1973-1990 cost stream by approximately 40 billion dollars. This represents a change of six percent to nine percent, depending on the discount rate employed.

Table A-22. Annualized Costs Assuming 40-Year Stationary Source Capital Amortization Period, 1973-1990 (millions of 1990 dollars).

	Annualized Costs		
Year	**at 3%**	**at 5%**	**at 7%**
1973	10,801	10,899	11,008
1974	12,875	13,108	13,366
1975	12,751	13,121	13,532
1976	13,338	13,891	14,504
1977	14,263	14,996	15,807
1978	13,778	14,690	15,695
1979	15,936	17,024	18,220
1980	18,091	19,368	20,771
1981	17,809	19,272	20,880
1982	16,670	18,316	20,123
1983	16,941	18,759	20,754
1984	17,836	19,803	21,960
1985	20,079	22,213	24,551
1986	18,544	20,809	23,288
1987	19,384	21,772	24,387
1988	19,203	21,706	24,446
1989	19,989	22,604	25,467
1990	20,546	23,268	26,247

Table A-23. Effect of Amortization Periods on Annualized Costs Discounted to 1990 (billions of 1990 dollars).

	Discount rate		
	3%	5%	7%
20-yr amortization period	417	523	657
40-yr amortization period	379	483	617

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